SSD94D0298

STRATEGIC AVIONICS TECHNOLOGY DEFINITION STUDIES

ELECTRICAL ACTUATION (ELA) SYSTEMS TEST FACILITY

September 1994

CONTRACT NAS9-18880
SUB TASK 3-1A3

Prepared by:

J. P. Rogers
Laboratories & Test

Approved by:

K. L. Cureton 9/29/94
K. L. Cureton
Advanced Programs Engineering

J R Olsen 9/29/94
J. R. Olsen, Manager
Mechanical & Electrical Systems
Laboratories & Test

Rockwell International
Space Transportation
Systems Division

ABSTRACT

Future aerospace flight vehicles will require the use of Electrical Actuation systems for flight control elements. This report presents a proposed ELA Test Facility for dynamic evaluation of high power linear Electrical Actuators with primary emphasis on Thrust Vector Control actuators. Details of the mechanical design, power and control systems, and data acquisition capability of the test facility are presented. A test procedure for evaluating the performance of the ELA Test Facility is also included.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION 1.0 - INTRODUCTION

1.1

Current high power linear actuators used for position control of aerospace mechanical elements, such as engine nozzle Thrust Vector Control (TVC), Elevon control, and rudder control use high pressure hydraulic fluid as the energy medium for operation. The high pressure hydraulic system presents problems with initial installation, service and maintainability, and fire and safety hazard especially in close proximity to LOX systems. Future aerospace development will focus on the replacement of these hydraulic power systems with electrical power systems and Electrical Actuators (ELA's). Several manufacturers are currently developing high power electrical actuators for aerospace applications.

Although the capability and performance of hydraulic actuators has been assessed with considerable laboratory and flight data, little data exists for performance of high power ELA's, especially for the dynamic environment of a TVC actuator. There is no known test facility that can simultaneously subject a high power position control ELA to the effects of inertial movement, applied load in various profiles, and friction effects.

Rockwell SSD Laboratories and Test's experience with large scale structural static and fatigue tests, dynamic tests, electrical power systems, high and low speed data acquisition, and extensive laboratory facilities provide a resource to develop and utilize an adaptable ELA Test Facility for high power ELA's.

This document presents a design for a test facility that can accommodate combined effects single motion axis testing for ELA's from 10 hp to 50 hp that can be used in aerospace applications including TVC.

1.2

The ELA Test Facility design uses the Shuttle TVC actuator requirements as its baseline and sizes its capabilities to allow a minimum 20% TVC growth potential for future aerospace systems. The facility is designed to be modular so various combinations of effects and conditions can be reproduced to evaluate ELA response. Figure 1 shows a block diagram of the test facility configuration. The shaded blocks are systems or hardware supplied by an ELA supplier.

The ELA is connected to a single axis pivot engine mass simulator that will duplicate the moment of inertia of the rotating structure positioned by the ELA. Two additional connections on the engine mass simulator are available to input applied moment loads to the engine simulator. The first connection is for the Friction Control System which can be installed to provide an adjustable opposing force to engine simulator motion. The second connection is for either The Air Load Profile System or the Constant Load System. These systems are installed separately depending on the required loading condition. The Structural Support System connects the reactions of the ELA , engine mass simulator pivot, and applied loads.

Position control for the ELA is provided by a power controller supplied by the ELA supplier. Facility electrical power is provided by a Laboratories and Test DC power supply.

Load control for the Air Load Profile Load System is provided by a servo system controller. Load control for the Constant Load System is provided by a mechanical pressure adjustment. Hydraulic power supply is provided by the Laboratories and Test pump station.

All sensors are recorded on the time based Data Acquisition System. Real time data displays and post test processing are available.

Details of the ELA Test Facility systems are described in separate sections of this document. ELA loads that are indicated in those sections are referenced to Shuttle geometry.

1.3

As noted previously the design standard for the ELA Test Facility is the Shuttle TVC actuator with a 20% minimum performance margin. The following list details the design performance of the test facility:

ELA power range -	10 - 50 hp
ELA moment arm range -	12 - 36 inches *
ELA stroke range -	within engine simulator limits
ELA length range -	unlimited
Engine simulator moment of inertia range -	2000 - 6000 slug -ft^2
Engine simulator motion range -	+/- 15 degrees
Maximum applied load -	2.4×10^6 in-lbs
Maximum profile load velocity -	17.5 deg/sec
Maximum constant load velocity -	35 deg/sec
Friction load range -	0.5×10^5 - 3.5×10^5 in-lbs
DC power supply capability -	0 - 350 V @ 300 amp max
Command signal profiles -	unlimited
Data acquisition speed -	> 1000 samples/sec/sensor

* Greater moment arms possible with structural modification

1.4

Various Rockwell D/284-300 personnel assisted in the preparation of this ELA Test Facility Design Data Book. The following list indicates the contributing personnel and the sections that were prepared.

Section 4.0 - Structural Support System............................... M. A. Simmons
J. H. Sexton

Section 5.0 - Engine Mass Simulator System........................ M. A. Simmons
J. H. Sexton

Section 6.0 - Electrical Power Control System....................... T. D. Tran

Section 7.0 - ELA Position and Air Load Command System... W. C. Roberts

Section 10.0 - Data Acquisition System.................................. S. T. Flemming

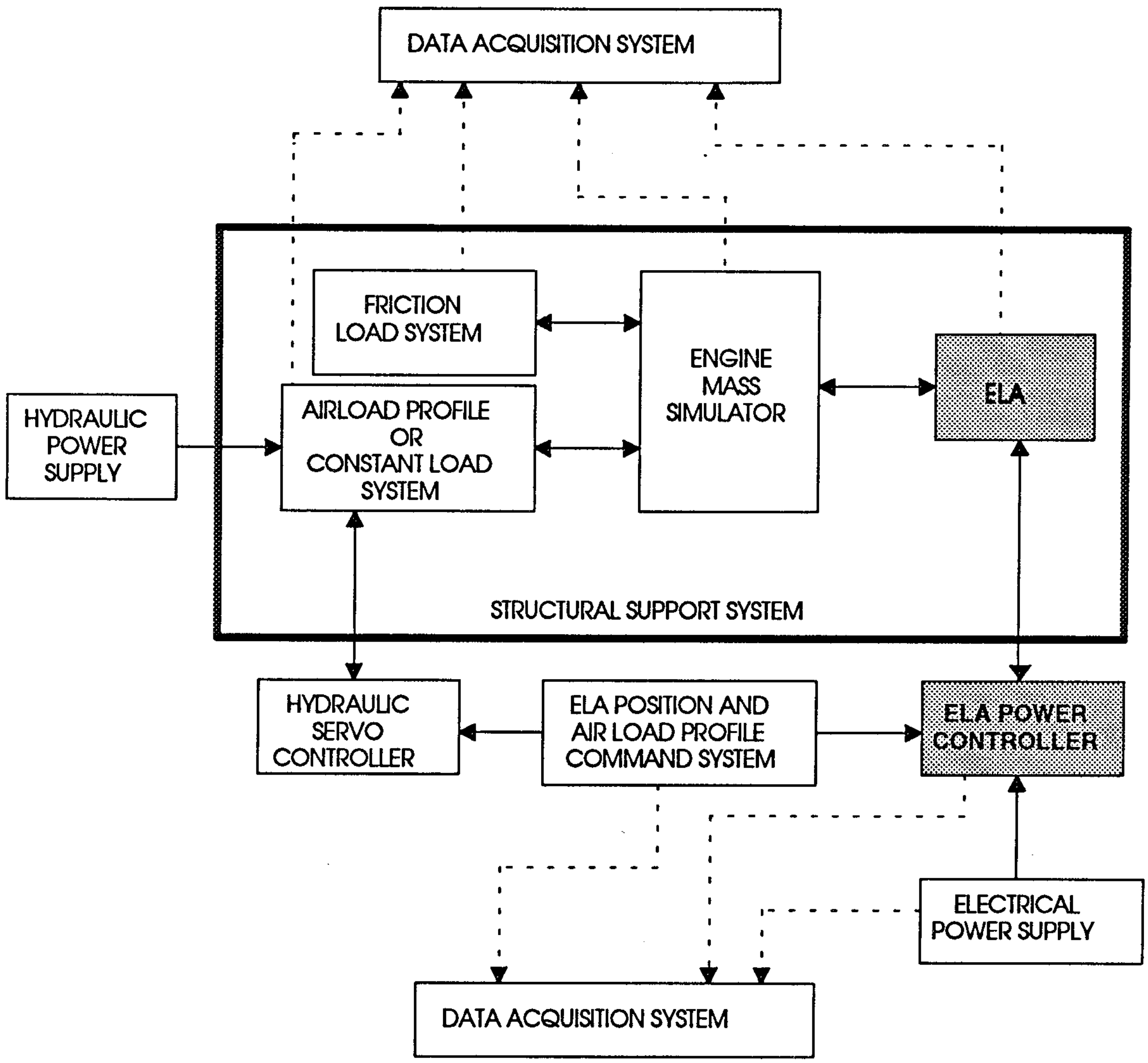


Figure 1 - ELA Test Facility Block Diagram

SECTION 2.0 - TEST FACILITY OVERVIEW

2.1

Figures 2 and 3 provide a pictorial overview of the ELA Test Facility as configured per this design data book. Figure 2 shows a complete pictorial view while Figure 3 removes some of the near side structure for clarity of inner components. Individual systems and parts are described in detail in later sections.

FOLDOUT FRAME

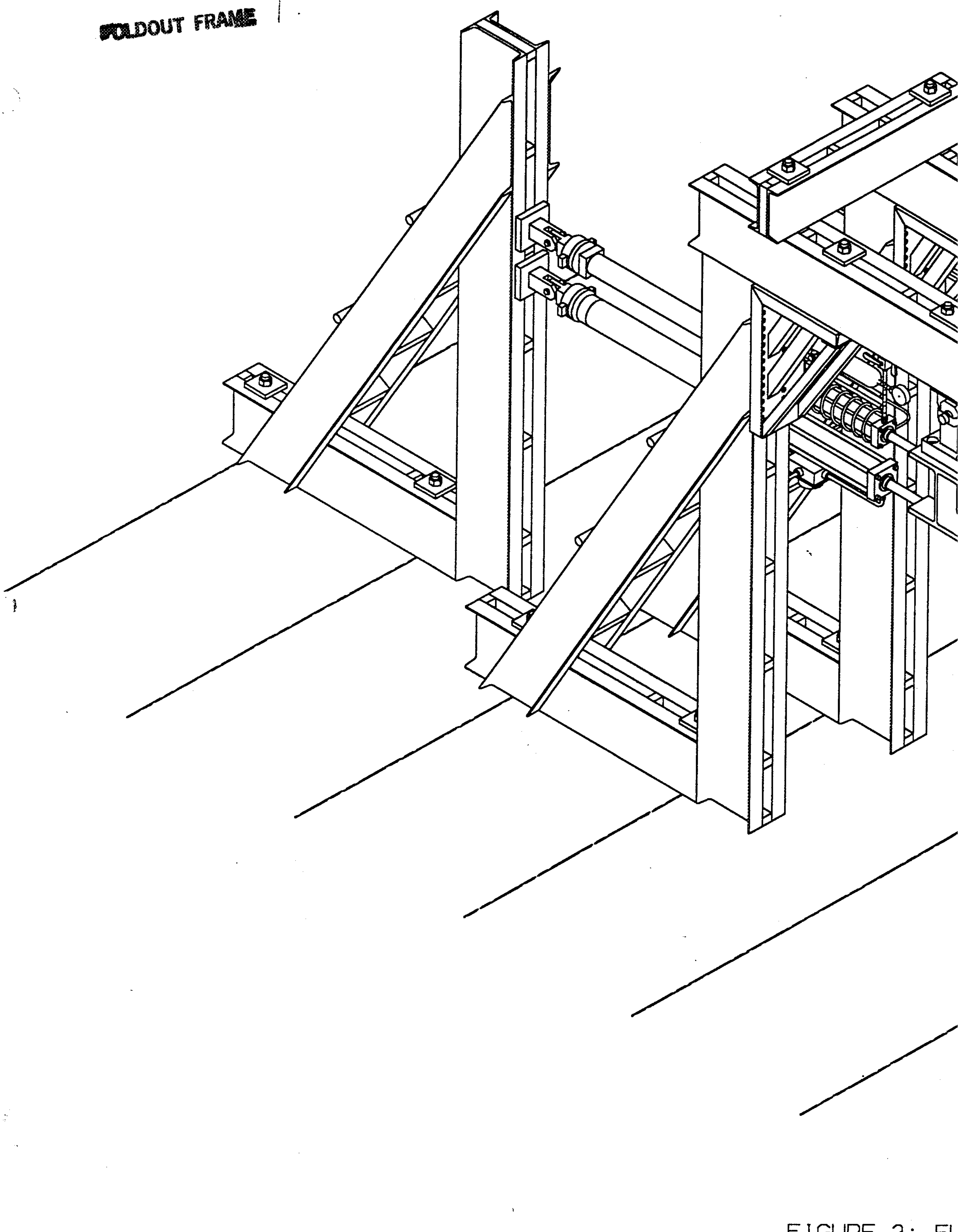
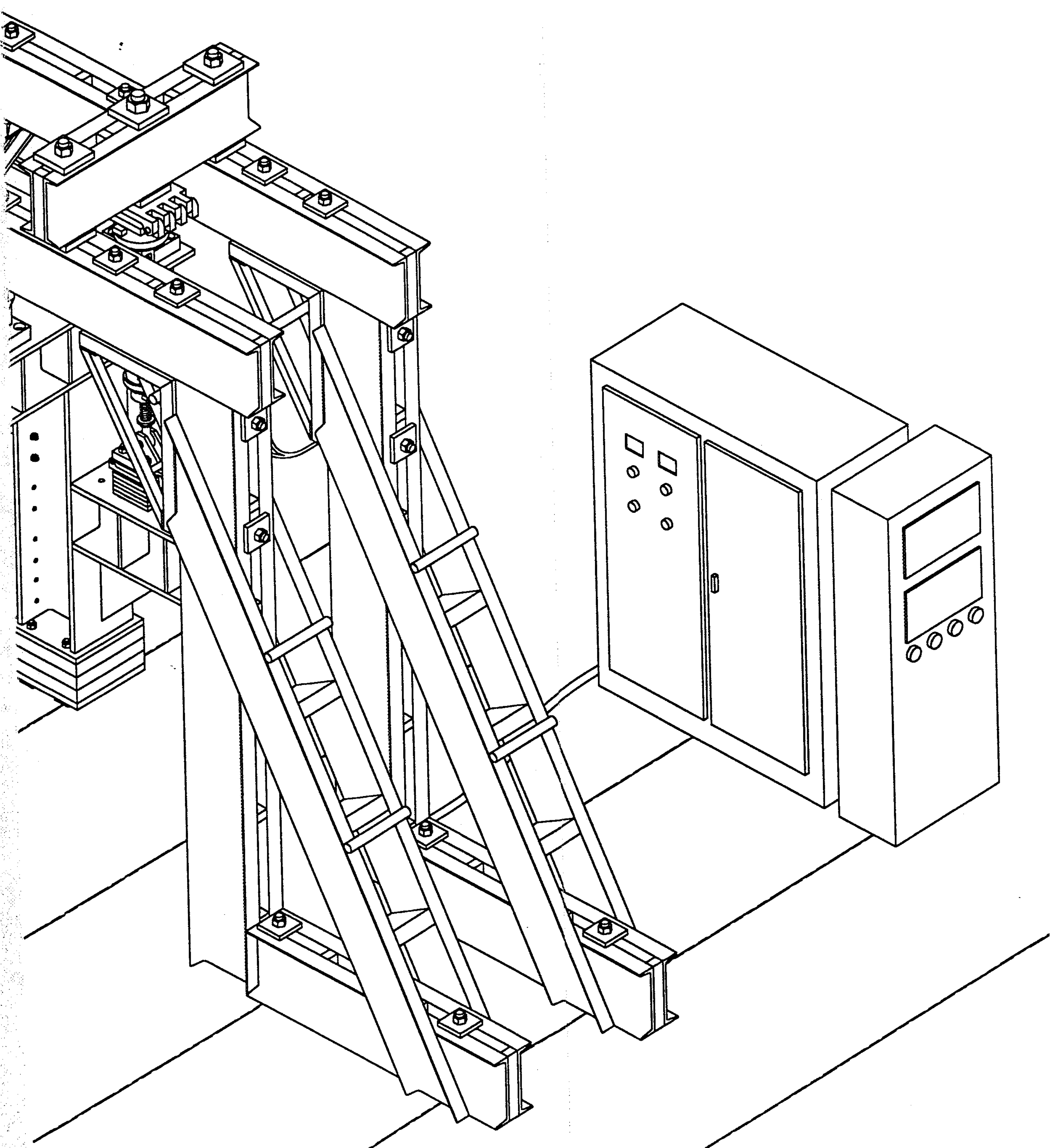


FIGURE 2; EL

LDOUT FRAME 2



A TEST FACILITY

FOLDOUT FRAME 1.

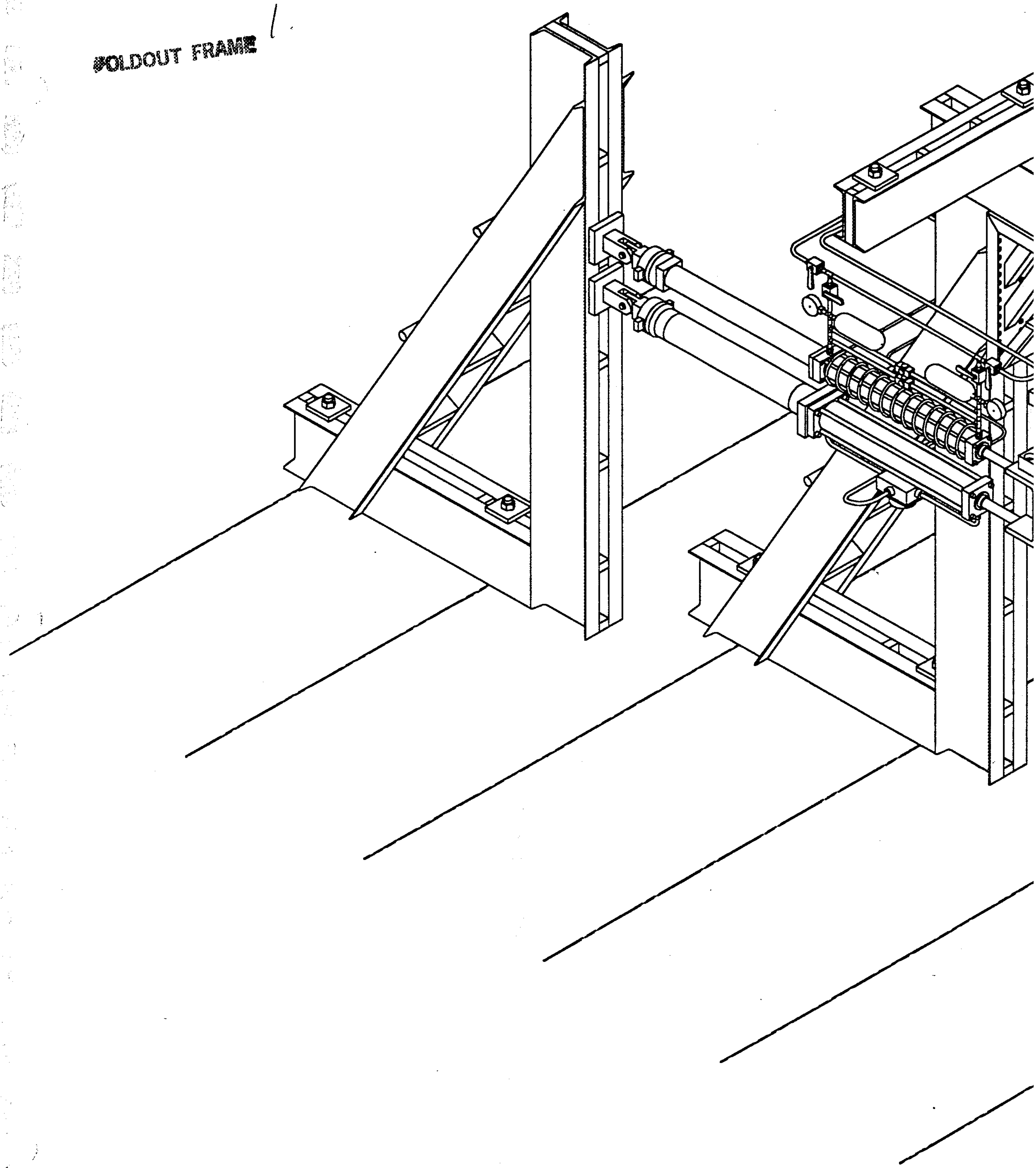
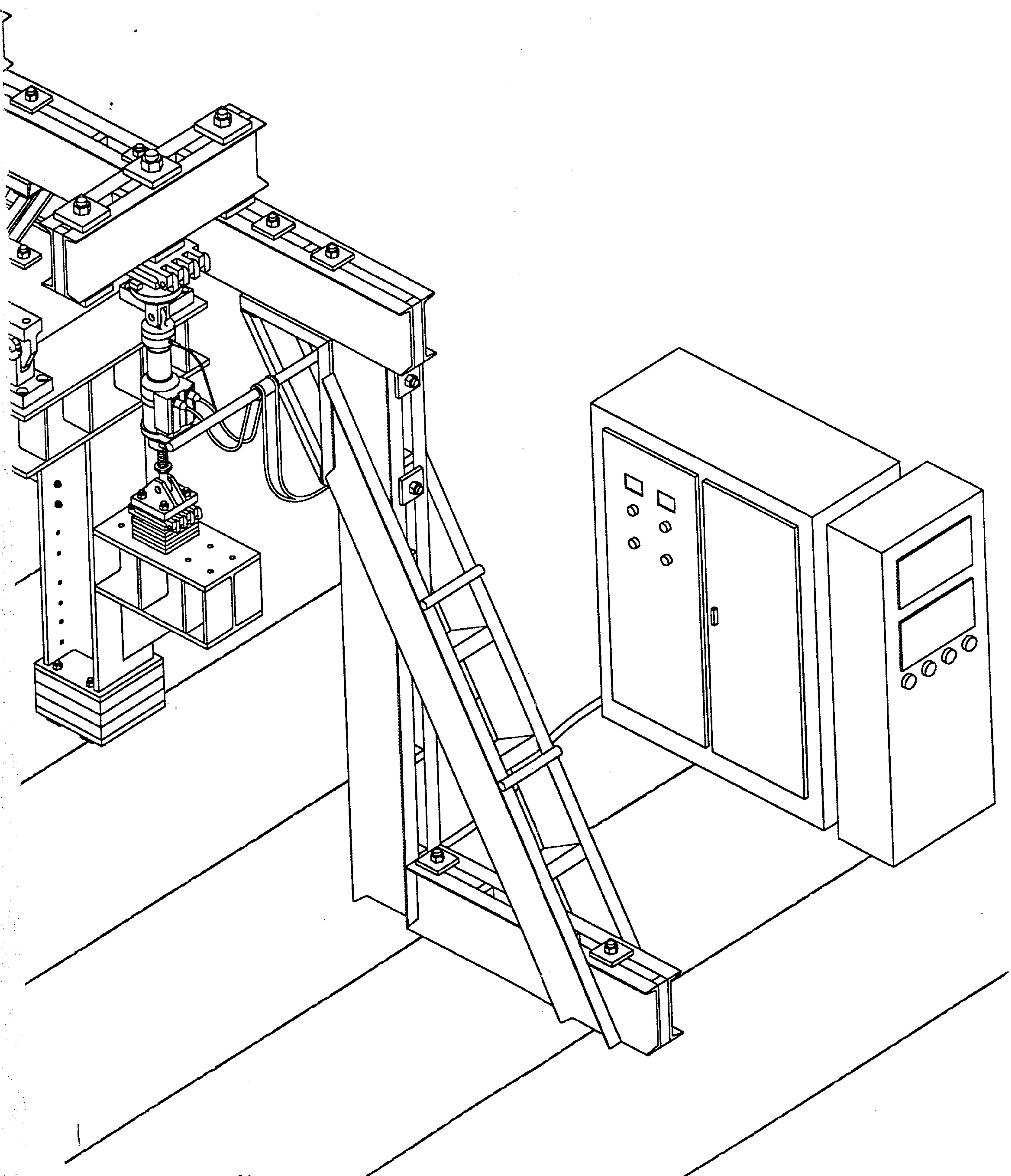


FIGURE 3: ELA TEST

FOLDOUT FRAME 2



SECTION 3.0 - ELA TEST FACILITY PARTS LIST

ITEM NUMBER	QUAN REQD	DESCRIPTION	FUNCTIONAL SECTION	DRAWING/PROPERTY NO.
-001		ELA Test Facility		
-002	5	136 in x 81 in Structural Steel Support "A" Frame	4.0	TT-13525
-003	2	15 in x 144 in Double Channel Steel Support Beam	4.0	15 D.C. 144-2
-004	1	12 in x 60 in Double Channel Steel Support Beam	4.0	12 D.C. 60-1.5
-005	1	15 in x 60 in Double Channel Steel Support Beam	4.0	15 D.C. 60-2.5
-006	4	36 in x 24 in Structural Steel Support "A" Frame	4.0	LP-88-420-021
-007	10	1.13 in dia Structural Connection Tie Rod	4.0	2.13.04-18-28
-008	20	1.50 in dia Structural Connection Tie Rod	4.0	2.13.04-24-22
-009	2	2.00 in dia Structural Connection Tie Rod	4.0	2.13.04-32-38
-010	1	2.50 in dia Structural Connection Tie Rod	4.0	2.13.04-36-24
-011	4	1.00 dia pin Structural Clevis	4.0, 5.0	LR 6470 -002
-012	4	AFB-16-E-52 Expando Bolt	4.0, 5.0	NA
-013	2	Custom Fitting Incorporating Self Aligning Roller Bearing	4.0	LR 6470-003
-014	1	Custom Clevis to Interface with Specific ELA	4.0	TBD
-015	1	TVC Structure Stiffness Simulation Flexure from FCHL	4.0	LR 1230-121
-016	1	Transducers Inc. 100k lbs Load Cell	4.0, 11.0	92201-8
-017	1	Engine Simulator Weldment	5.0	LR 6470-004
-018	2	Structural Clevis	5.0	LR 6470-005
-019	1	Custom Clevis to Interface with Specific ELA	5.0	TBD
-020	1	Engine Stiffness Simulation Flexure	5.0	TBD
-021	1	Engine Simulator Angular Position Transducer	5.0, 11.0	NA
-022	1	0-350V DC, 300 Amp Power Supply	6.0	N0384374
-023	2	0-300 Amp Current Measurement Shunt	6.0, 11.0	NA
-024	2	0-350 V DC Voltage Transducer	6.0, 11.0	NA

Table 1 - Test Facility Parts List

SECTION 3.0 - ELA TEST FACILITY PARTS LIST

ITEM NUMBER	OWNER	EXISTING ITEM?	PURCHASED ITEM PART NO.	PROPOSED MATL SUPPLIER	ESTM MATL COST $/EA
-001					
-002	NASA	YES	NA	NA	NA
-003	NASA	YES	NA	NA	NA
-004	NASA	YES	NA	NA	NA
-005	NASA	YES	NA	NA	NA
-006	NASA	YES	NA	NA	NA
-007	NASA	YES	NA	NA	NA
-008	NASA	YES	NA	NA	NA
-009	NASA	YES	NA	NA	NA
-010	NASA	YES	NA	NA	NA
-011	NASA	YES	NA	NA	NA
-012	NASA	YES	NA	NA	NA
-013	NA	NO	22312-VJ	Ryerson Metals/ Torrington	$400
-014	NA	NO	NA	Ryerson Metals	$200
-015	NASA	YES	NA	NA	NA
-016	NASA	YES	NA	NA	NA
-017	NA	NO	NA	Ryerson Metals	$500
-018	NA	YES	NA	NA	NA
-019	NA	NO	NA	Ryerson Metals	$200
-020	NA	NO	NA	Ryerson Metals	$300
-021	NA	NO	RT 9420-0R25	Celesco	$350
-022	NASA	YES	NA	NA	NA
-023	NA	NO	PRO 300	Quality Electric	$276
-024	NA	NO	1-022-C-DC	Arga Controls	$361

Table 1 - Test Facility Parts List

SECTION 3.0 - ELA TEST FACILITY PARTS LIST

ITEM NUMBER	QUAN REQD	DESCRIPTION	FUNCTIONAL SECTION	DRAWING/PROPERTY NO.
-025	2	Type "T" Thermocouple Transmitter	6.0, 11.0	NA
-026	1	Cyber II Load Control System	7.0	SO 065284
-027	2	Miller 5 in Bore x 36 in Stroke Single-ended Hydraulic Cylinder	8.0, 9.0	H52B-5-36
-028	2	Cylinder Extension	8.0, 9.0	LR 6470-006
-029	2	Transducers Inc. 50K lbs. Load Cell	8.0, 9.0, 11.0	U492-50K-5307
-030	6	Clevis	8.0, 9.0, 10.0	LR 6470-007
-031	1	Moog Model 72-103 Servo Valve	8.0	NA
-032	1	Cyber Model 9410 Servo Controller	8.0	SO 065269
-033	2	Manually Operated 4-Way Valve	9.0, 12.0	NA
-034	1	Pilot Operated Relief Valve	9.0	NA
-035	1	Denison Proportional Pressure Control	9.0	NA
-036	1	2 1/2 Gal Hydraulic Accumulator	9.0	NA
-037	1	5000 psig Pressure Gage	9.0	1279S-5000
-038	1	Miller 3 1/4 inch Bore x 18 in Stroke Double-ended Hydraulic Cylinder	10.0	NA
-039	2	Adjustable Relief Valve	10.0	NA
-040	2	10 Cu. in. Hydraulic Accumulator	10.0	NA
-041	2	3000 psig Pressure Gage	10.0	1279S-3000
-042	1	Cylinder Reaction Structure	10.0	LR 6470-008
-043	1	Transducers Inc. 10K lbs. Load Cell	10.0, 11.0	WTC-PF492-CD-10K-5307
-044	4	Robbins Aviation Hand Valve	10.0	SSN6-250-4T
-045	1	Laboratory Data Acquisition System	11.0	JO111508
-046	1	Cyber Full Bridge Signal Conditioning	11.0	JO111523
-047	1	Miller 7 inch Bore x 12 inch Stroke Hydraulic Cylinder	12.0	H52B-7-12
-048	1	Valve Limit Adjustment Fixture	12.0	LR 6470-009

Table 1 - Test Facility Parts List

SECTION 3.0 - ELA TEST FACILITY PARTS LIST

ITEM NUMBER	OWNER	EXISTING ITEM?	PURCHASED ITEM PART NO.	PROPOSED MATL SUPPLIER	ESTM MATL COST $/EA
-025	NA	NO	2B52A-1-T-02	Analog Devices	$297
-026	NASA	YES	NA	NA	NA
-027	NASA	YES	NA	NA	NA
-028	NA	NO	NA	Ryerson Metals	$250
-029	NASA	YES	NA	NA	NA
-030	NASA	YES	NA	NA	NA
-031	NASA	YES	NA	NA	NA
-032	NASA	YES	NA	NA	NA
-033	NA	NO	147R3WC3	Barksdale	$1,553
-034	NA	NO	R5V12-413-12-A1	Denison	$430
-035	NASA	YES	SEO.3-21042	Denison	$1,222
-036	NASA	NO	800730	Greer Hydraulics	$715
-037	NASA	YES	NA	NA	NA
-038	NA	NO	DH-52-B-2-N-3.25-18-1.375-N-11-9	Miller Fluid Power	$850
-039	NA	NO	5132B-6MP-800	Circle Seal	$120
-040	NASA	NO	800010	Greer Hydraulics	$280
-041	NASA	YES	NA	NA	NA
-042	NA	NO	NA	Ryerson Metals	$250
-043	NASA	YES	NA	NA	NA
-044	NASA	YES	NA	NA	NA
-045	NASA	YES	NA	NA	NA
-046	NASA	YES	NA	NA	NA
-047	NASA	YES	NA	NA	NA
-048	NA	NO	NA	Ryerson Metals	$250

Table 1 - Test Facility Parts List

SECTION 4.0 - STRUCTURAL SUPPORT SYSTEM

4.1

The Structural Support System is designed to support and react the loads originating from the ELA, Engine Mass Simulator System, Friction Control System, Air Load Profile Load System, and Constant Load System (see Figures 4 and 5). The system was designed to be set up in the structural test high bay section of Bldg. 288 at Rockwell SSD and utilize the existing structural tie-down floor, test frame works, and "erector set" load beams.

4.2

The Bldg. 288 structural floor has heavy interconnecting steel beams and attachment rails embedded into a thick concrete slab providing high load capability and rigidity. The steel beams are connected to deep piers which can withstand high pull-out loads. The test frame works are bolted to this structural floor allowing high strength, ease of assembly, and reposition capability. Both the load beams and frame works are slotted, enabling a bolted interconnection with almost infinite positioning adjustments.

4.3

Bolted clevises attached to the test frame works and beams will provide a connection point for the load systems, engine simulator, and ELA. The -011 clevises used for the connection of the Friction Control System, Constant Load System, and Air Load Profile System are designed to be used in conjunction with a Teflon lined spherical bearing and expanding bolt (-012). The expanding bolt will eliminate the mechanical slop in the clevis and bearing while the Teflon lined bearing race will minimize rotation friction.

The fittings which connect the Engine Mass Simulator (-013) will have high load capability self aligning roller bearings installed to minimized the friction at the engine pivot. Accurate dynamic load duplication will require all friction loads to be applied by the Friction Control System only.

The attachment for the ELA (-014) will be a custom clevis fabricated to the specification of the ELA manufacturer.

4.4

A 100K lbs. load cell and structural flexure are installed in line with the ELA. The load cell output will be continuously recorded by the Data Acquisition System during test operations. The structural flexure will simulate the stiffness and deflections of the backup structure expected to support the ELA in an operational environment. The -015 flexure indicated is a flexure used for TVC structure simulation in the Rockwell FCHL (Flight Controls Hydraulic Laboratory) used for the Shuttle development program. The FCHL facility, currently being dismantled for salvage, contains a variety of other flexures used for other control elements.

4.5

The structural load beam supporting the ELA attachment (-005) can be easily repositioned laterally and, by using spacers between load beams, easily positioned vertically and/or rotated. This adjustment will allow for a wide range of ELA actuator geometry and length to be installed and tested.

FOLDOUT FRAME

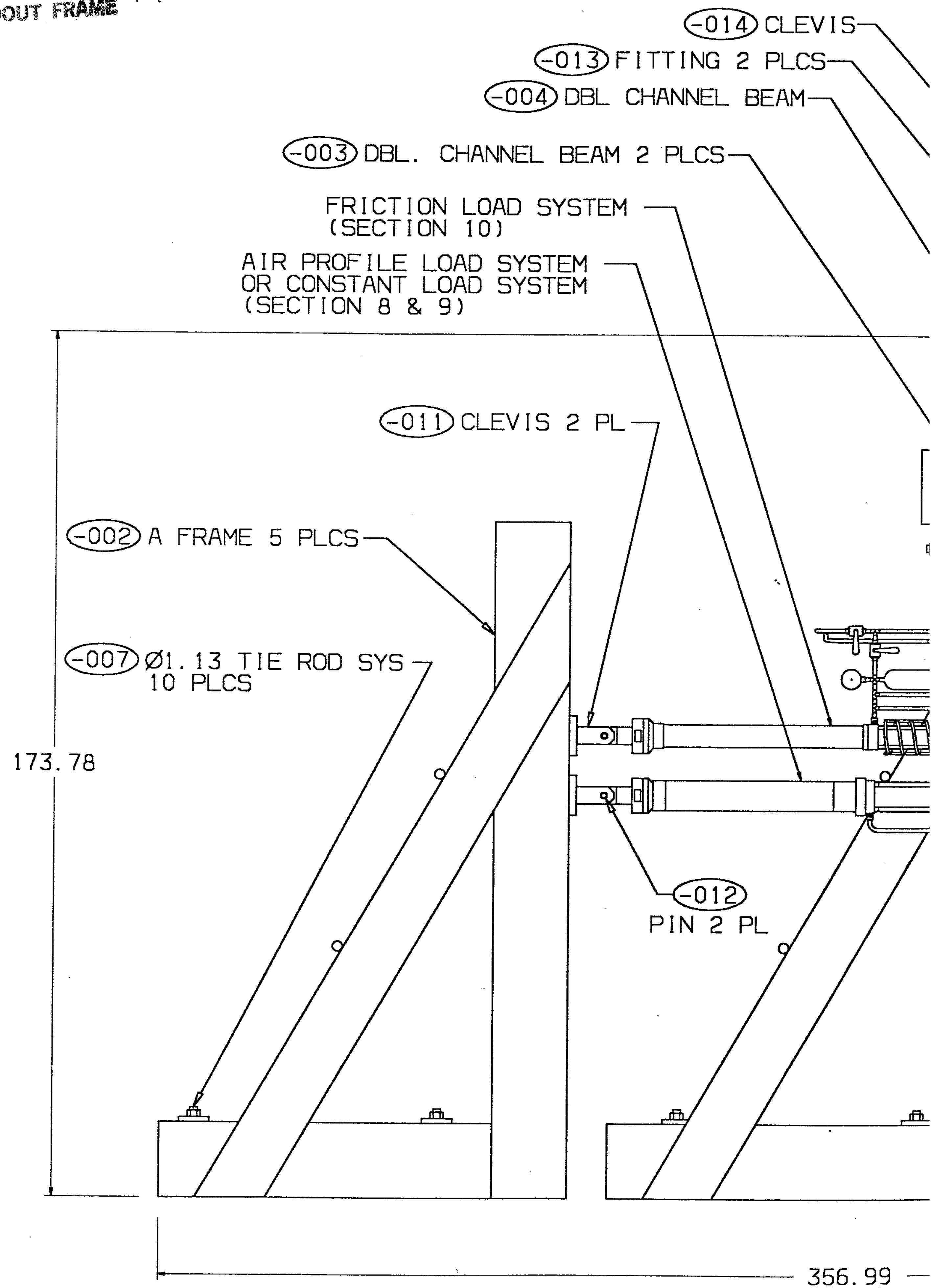
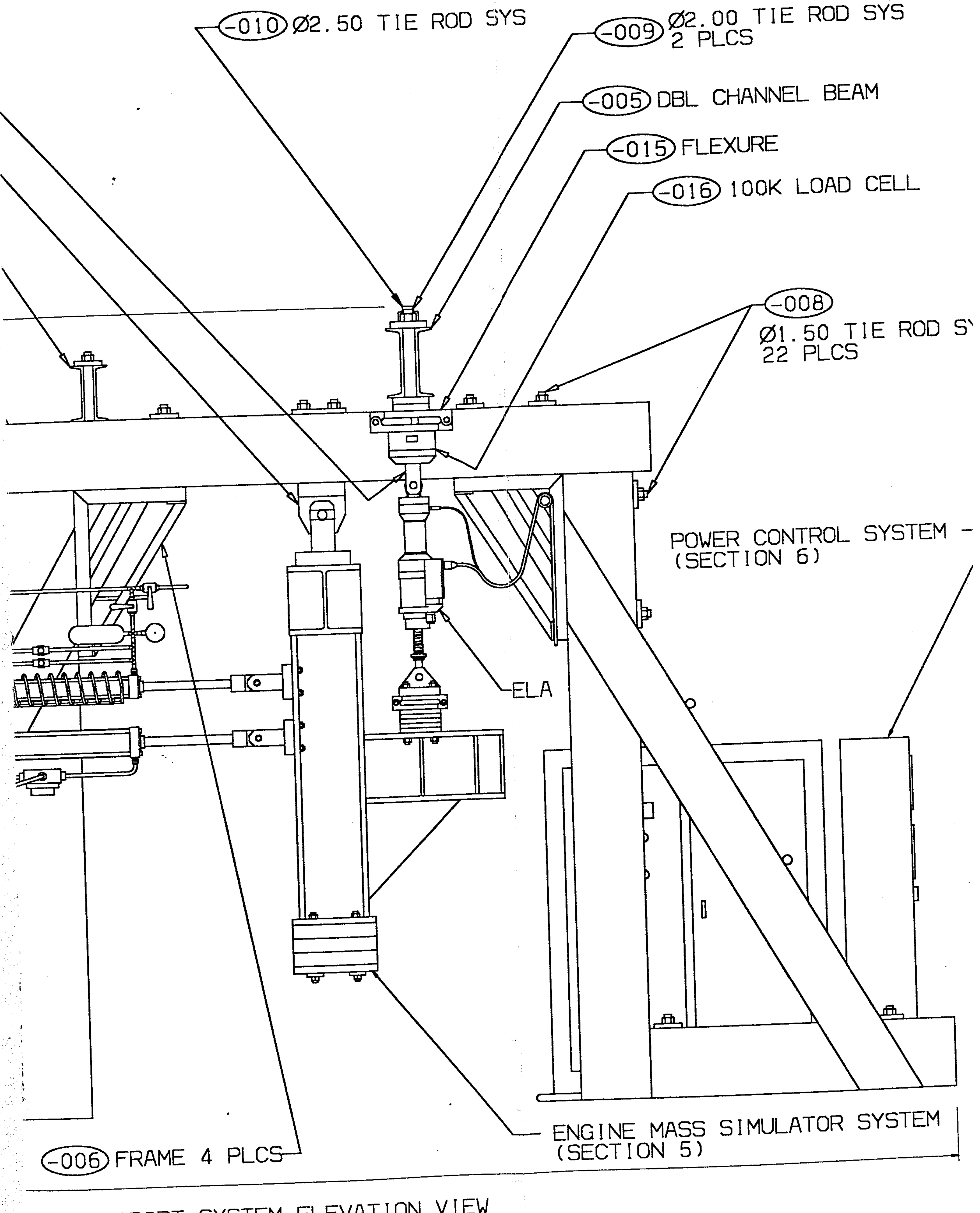


FIGURE 4; STRUCTU


-010 Ø2.50 TIE ROD SYS
-009 Ø2.00 TIE ROD SYS
2 PLCS
-005 DBL CHANNEL BEAM
-015 FLEXURE
-016 100K LOAD CELL
-008 Ø1.50 TIE ROD S
22 PLCS
POWER CONTROL SYSTEM -
(SECTION 6)
ELA
ENGINE MASS SIMULATOR SYSTEM
(SECTION 5)
-006 FRAME 4 PLCS
SYSTEM ELEVATION VIEW

FOLDOUT FRAME 1.

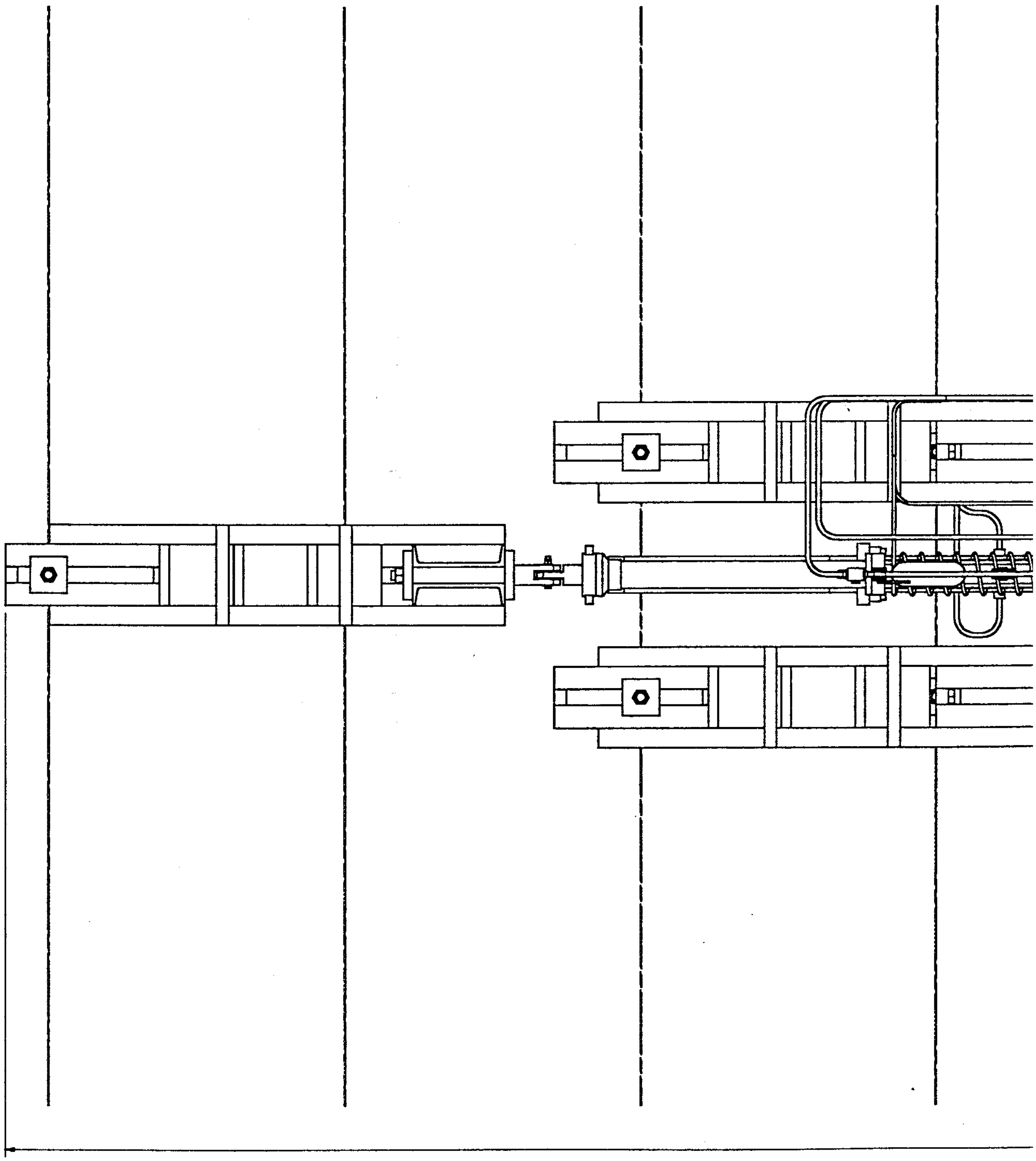
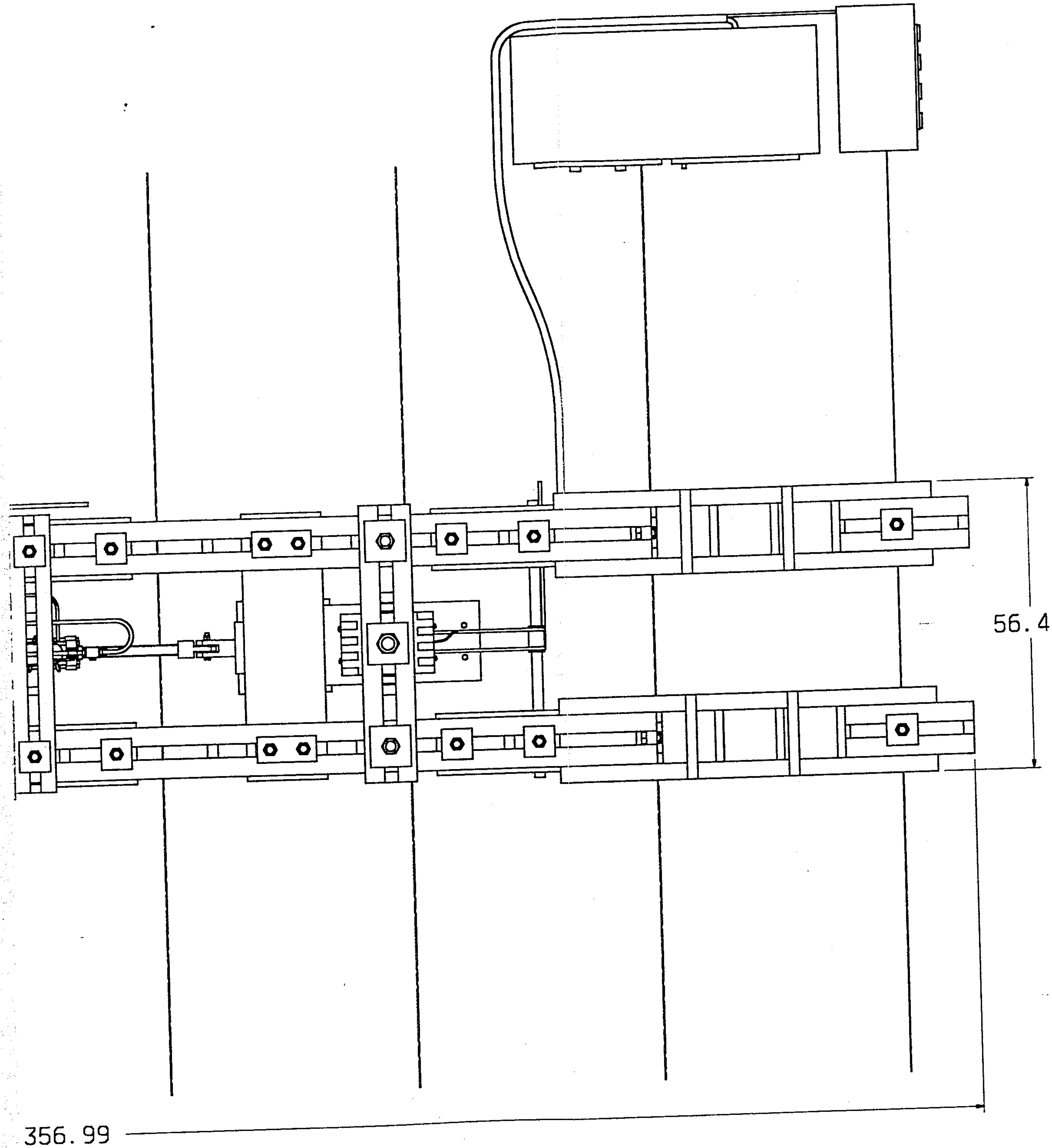


FIGURE 5; STRUCTURAL



SUPPORT SYSTEM PLAN VIEW

SECTION 5.0 - ENGINE MASS SIMULATOR SYSTEM

5.1

The Engine Mass Simulator System is designed to simulate the mass moment of inertial of a gimbaled rocket motor and nozzle assembly and the TVC actuator attachment to that assembly. The system is designed to simulate a range of both mass moments and actuator attachments (see Figure 6) for duplication of a variety of possible ELA installations.

5.2

The Engine Mass Simulator is configured with attachments for an ELA, the Friction Control System, and either the Air Load Profile Load System or the Constant Load System. The ELA attachment is made on a platen area of the simulator which allows lateral moment arm and position adjustments. Vertical position of the ELA attachment can be adjusted will spacers on the platen.

The attachments for the load systems are made with the same clevises and expanding bolts as noted in Section 4.3. The elimination of mechanical slop will greatly enhance the performance of the system. Although the load systems attachment clevises are shown in locations that optimize force and motion for simulation of a Shuttle TVC configuration, the clevises can be repositioned for specialized force/motion requirements. The performance specifications noted in Section 1.0 are referenced to the locations shown.

5.3

The Engine Simulator attachment to the Structural Support System is a single rotation connection with two pivot points. The use of two pivot points prevents instability and "Z" axis rotations during load and deflection reversals. As noted in Section 4.3 the pivot connection will use high capacity roller bearings to minimize friction.

5.4

The adjustment of mass moment of inertia is accomplished by securely bolting lead weights to the bottom of the Engine Simulator with through tie rods. The baseline Shuttle mass moment of inertia is 4033 slug-ft^2. Without weights, the basic simulator structure has a mass moment of inertia of approximately 2000 slug-ft^2. The addition of 2000 lbs. of lead weights to the bottom of the simulator will change the MMI to >6000 slug-ft^2. Intermediate MMI values are obtained by incrementally adjusting weights as required.

5.5

The -019 attachment clevis for the ELA will be a custom fabrication based on ELA manufacturer requirements. The -020 flexure shown in Figure 6 does not exist but is shown as a possible installation for engine CG to TVC actuator stiffness requirements.

5.6

A rotational transducer will be attached to the Engine Mass Simulator pivot point and referenced to the Structural Support System. The transducer will measure angular deflection of the Engine Simulator. The output of the transducer will be continuously recorded during test operations.

FOLDOUT FRAME 1.

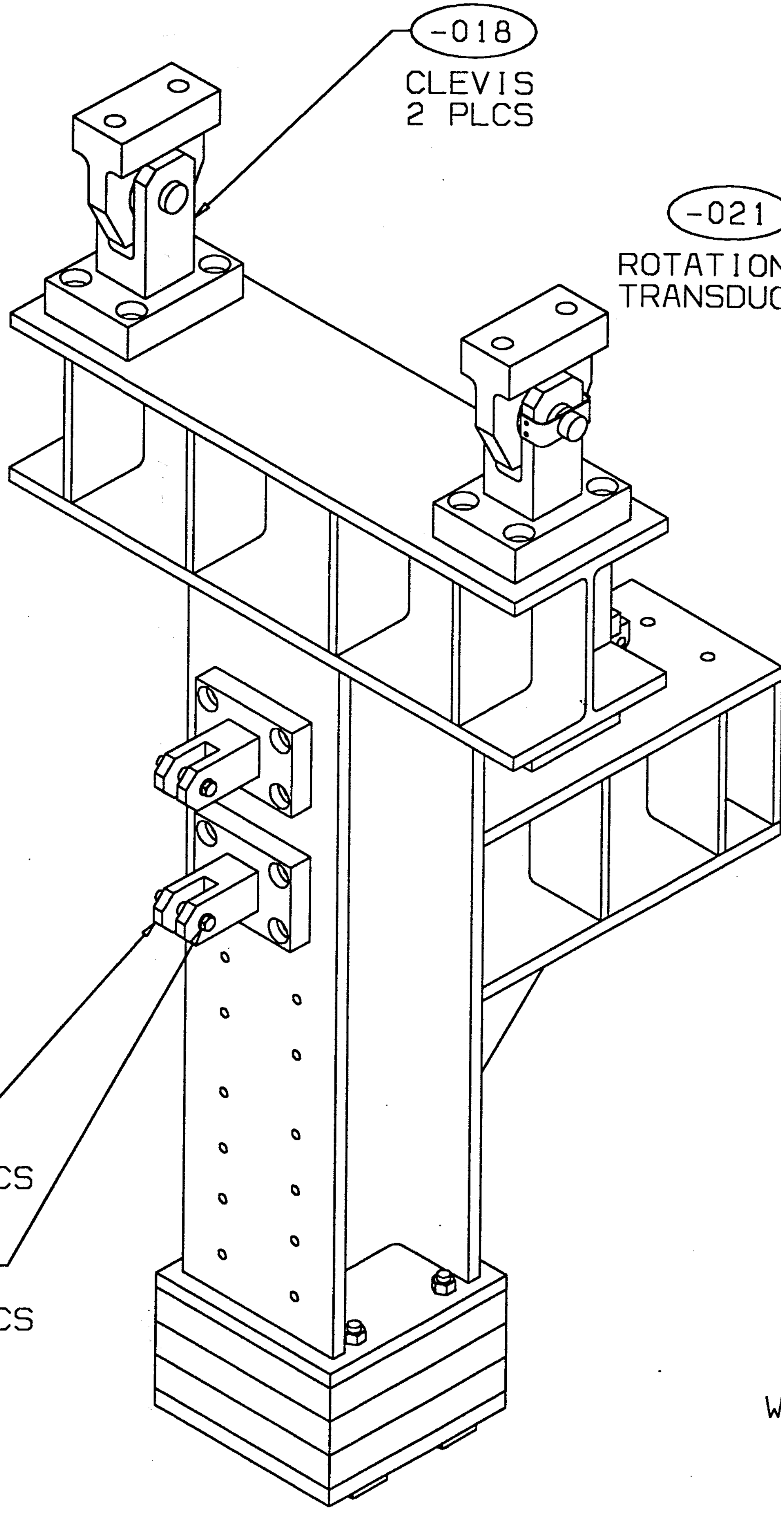
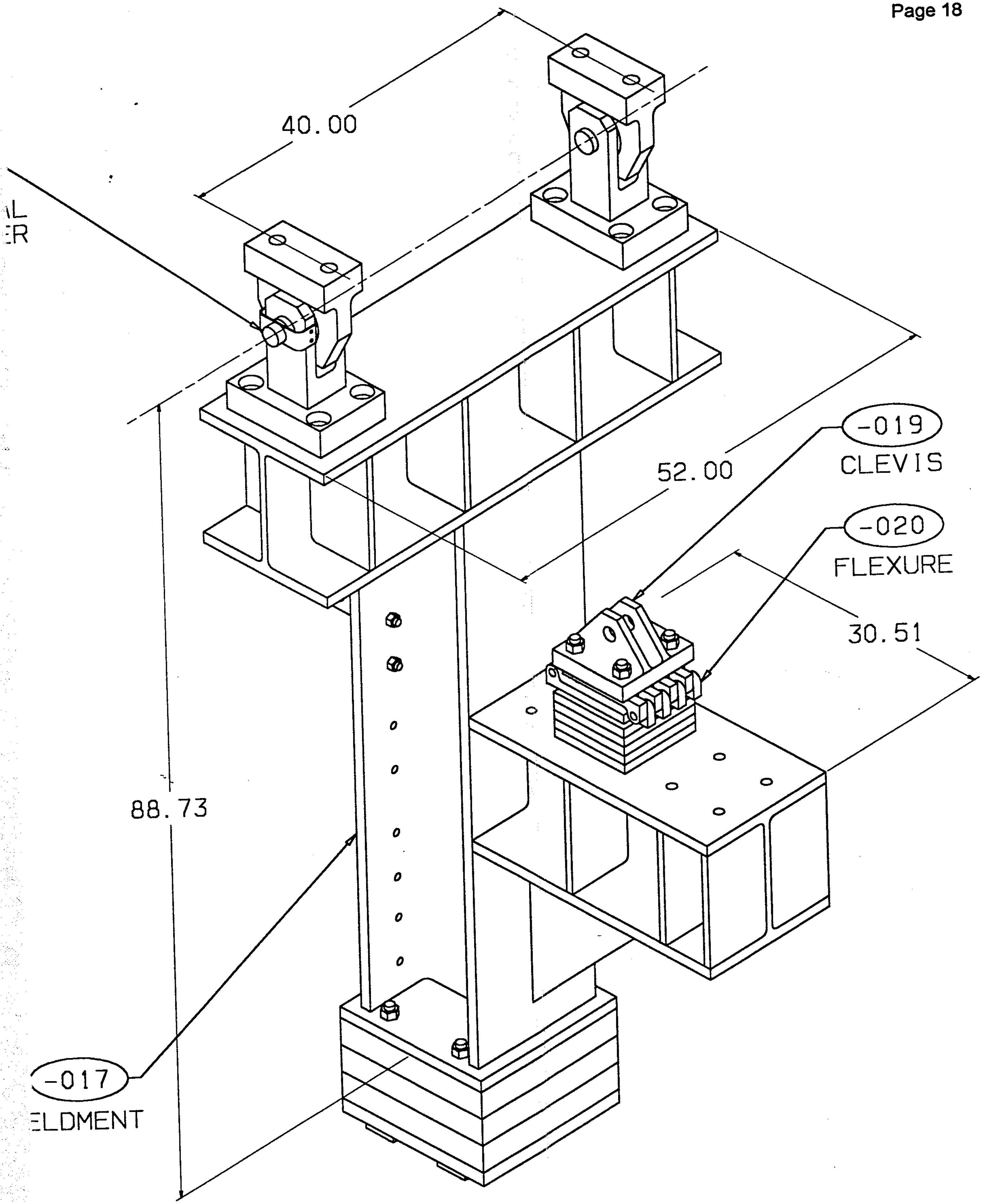


FIGURE 6; ENGINE M



ASS SIMULATOR SYSTEM

SECTION 6.0 - ELECTRICAL POWER CONTROL SYSTEM

6.1

The Electrical Power Control System is designed as a complete power delivery and control system for the ELA. The system is configured with both dedicated test facility components and ELA control components supplied by an ELA manufacturer (see Figure 7, manufacturer supplied components are shown shaded). The system design assumes the ELA and ELA power controller are two separate pieces which is the expected design approach of current known ELA systems. If other ELA system configurations are tested it may require changes to the Electrical Power Control System to provide ELA performance data. The total system power supply capability will support ELAs producing >50 horsepower.

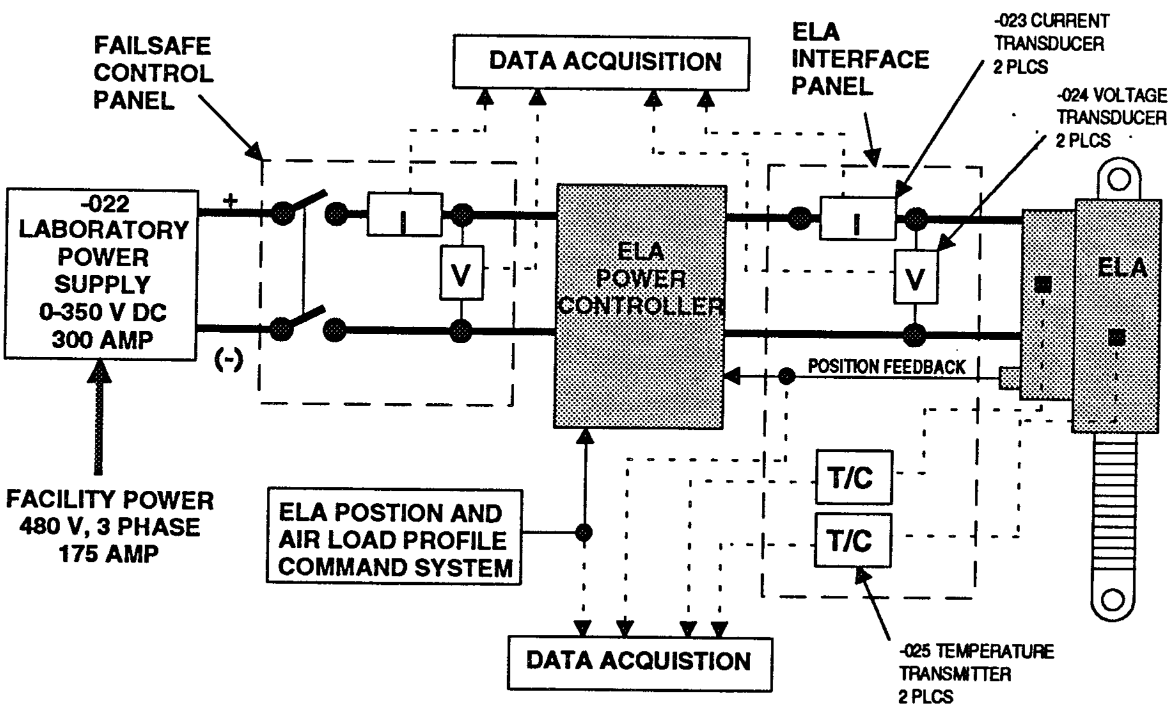


Figure 7 - Electrical Power Control System

6.2

All ELA power will come from an existing DC power supply rated at 105 kilowatts (81 kilowatts, 109 hp @ 270 VDC). The power supply will be connected to a 480 VAC, 3 Φ, 175 A service installed as a dedicated circuit at the ELA Test Facility. The power supply has an adjustable voltage output and can be set to 270 VDC or other required ELA voltage < 350 VDC.

6.3

The power supply will be connected to a fail-safe control panel which can be configured to interrupt power at preset voltage and current limits required by the ELA manufacturer's power controller. The fail-safe control panel will use a programmable circuit that will monitor voltage and current transducers and open a high current relay if preset values are exceeded. The voltage and current transducers will also be connected to the Data Acquisition System for continuous recording during test operations.

6.4

The ELA Power Controller, supplied by the ELA manufacturer, will receive the electrical supply, the position command signal from the ELA Position and Air Load Profile Command System, and the position feedback signal from the ELA. Using these inputs, the power controller will determine the direction and magnitude of the voltage and current output the ELA requires for proper position tracking. The ELA position command signal will be connected to and simultaneously recorded by the Data Acquisition System.

6.5

Interconnecting the ELA Power Controller and ELA will be an ELA interface panel. This panel exists to enable data acquisition to be acquired on ELA performance. It will provide Data Acquisition System connections for ELA voltage and current instrumentation and a connection for simultaneous recording of the ELA position sensor feedback. The panel will also include Type "T" Thermocouple Transmitters for recording various ELA temperatures. Final configuration of the interface panel can only occur after obtaining ELA cabling and connector information and hardware for a specific ELA from the ELA manufacturer.

6.6

The ELA Test Facility area will be restricted to all personnel when the -022 Laboratory Power Supply is active. The test area will be cordoned off with signs indicating hazardous testing.

SECTION 7.0 - ELA POSITION AND AIR LOAD PROFILE COMMAND SYSTEM

7.1

The ELA Position and Air Load Profile Command System uses an existing Cyber II Load Control System to provide a time based analog set point command signal to both the ELA Power Controller and the hydraulic servo controller in the Air Load Profile Load System. Except for the common timing base for both signals, each signal is totally independent and be may varied to any type of wave form or profile that is required for the test. The system operates by specifying a programmed series of digitally stored percentage values or "steps" and the time required to transition from one percentage value to the next. The percentage values can vary from -100% to +100% and can change by any amount from step to step. Each command channel has its own separate step value for each time increment.

These step transitions are processed into smooth transitions from step value to step value and transmitted to the Digital to Analog Conversion (DAC) . The DAC converts the +/- 100% step value range proportionally into a maximum +/- 10 V DC output to the ELA Power Controller and Air Load Profile System (see Figure 8). The ELA Power Controller and Air Load Profile System are each configured and calibrated to equate the maximum +/- 10 V DC command signal to some maximum displacement or air load.

The specified time increment for the transition from one step value to the next is variable over a wide range. The specified time increments can be the same for all steps or they can vary for one or all steps. For duplication of random or rapidly changing wave forms or profiles, a small transition time value will enable a more accurate replication of the required time based profile. The minimum time transition available with this system is .040 seconds which will adequately support the duplication of square wave or step function command signal requirements.

7.2

The Test Control and Process Panel (see Figure 8) is used to input small profile program steps for subsequent RUN/HOLD/RAMP (to zero command)/STOP testing procedures. Wave form initiation can be input for square wave, step function, triangle wave, ramp and hold (up and down), sinusoidal, and small profiles of 1-256 steps. If a "Cycle Counts" program is activated, software counters stored under program control can provide status of the wave form or profile steps completed. The step transition smoothing function generation of 2048 intermediate step pulses is provided by a Voice Control Oscillator (VCO) via timer control logic for subsequent wave form or profile generation output to a DAC channel module.

Command wave form and profile storage is provided by on-board memory. The recall of smaller wave forms or profiles is provided by uploading the step and time data file from a Floppy Disk sub-system. Larger profile step files are stored on 9 track magnetic tape drives and uploaded as required. Both the Floppy Disk system and magnetic tape drive can be used for importing/exporting programs and profile step data files for subsequent testing.

Central processing is provided by a 16-bit CPU with full-duplex asynchronous communication interface, static RAM, and 32K dynamic RAM. Direct Memory Access (DMA) is provided for data handling.

The digital to analog wave form conversion circuits include a DAC Module connected with external circuitry to provide bipolar operation, an analog scaling input from a master percent span control to a multiplying DAC, and a bridge amplifier to condition the selected analog input. The multiplying DACs use the analog input and a 12-bit digital input to provide the +/- 10 V DC command signal to the ELA Power Controller and the Air Load Profile System.

7.3

The +/- 10 V DC command outputs are directly connected to the Data Acquisition System. The high magnitude input impedance of the Data Acquisition System alleviates any degradation of the command signals. The command signals will be continuously recorded during test operations

7.4

The Cyber II Load control System is located in Bldg. 288 and used to support test operations in the high bay area proposed for the ELA Test Facility location. Existing cable connections and communications are in place to interface with the test facility.

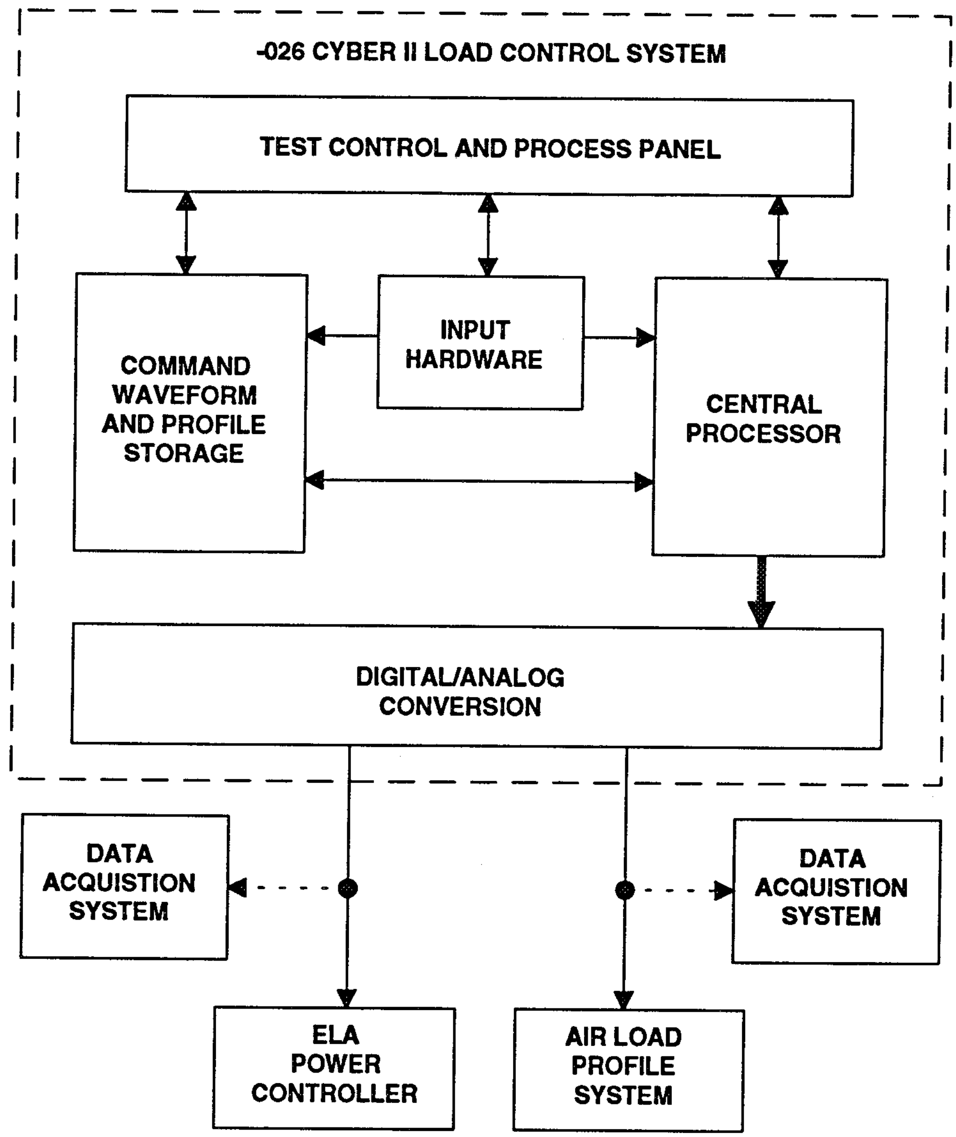


Figure 8 - ELA Position and Air Load Profile Command System

SECTION 8.0 - AIR LOAD PROFILE LOAD SYSTEM

8.1

The Air Load Profile Load Control System is designed to apply varying time based load profiles to the engine simulator and ELA. The system will be able to apply repeating load profiles (sinusoidal, saw tooth, etc.) or fully randomized load profiles simulating flight air loads. The system is designed to control time based load application with engine simulator velocities from 0 - 17.5 deg/sec.

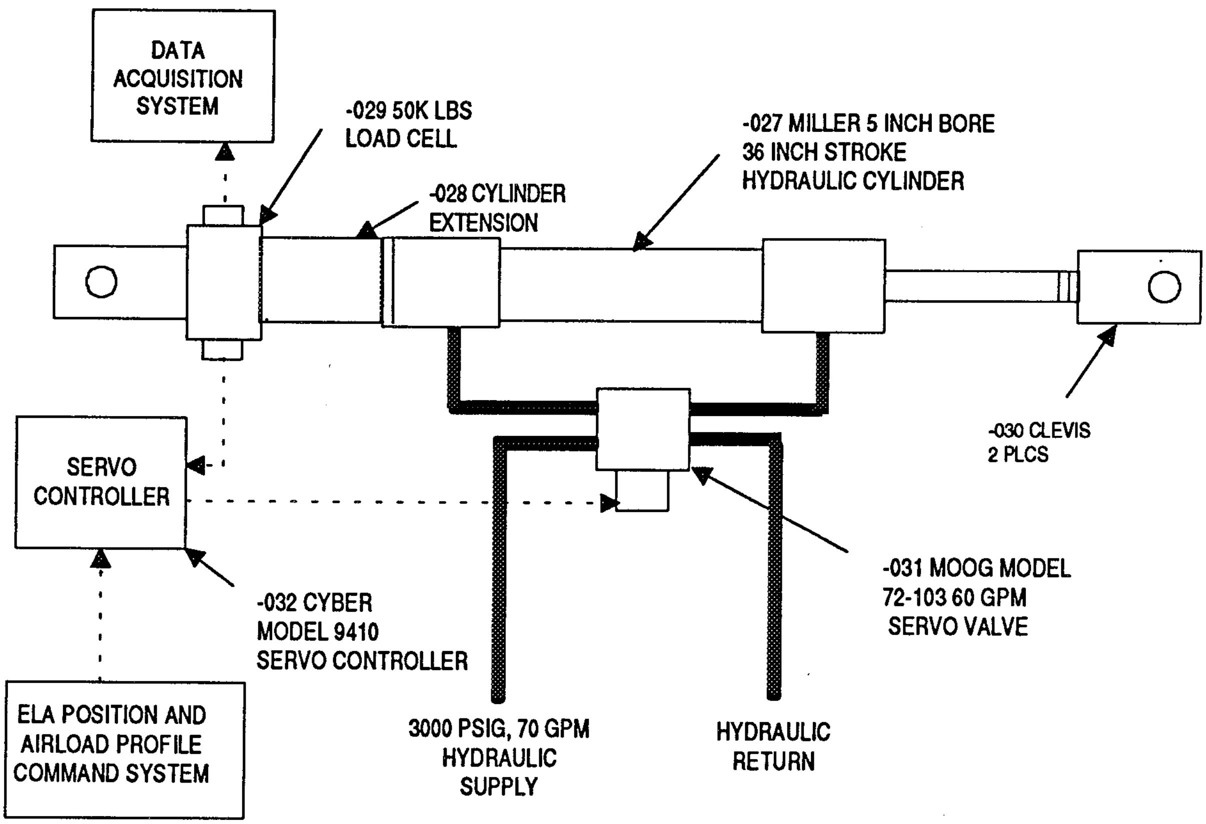


Figure 9 - Air Load Profile Load System

8.2

The system is configured as an active servo-hydraulic command/feedback process loop incorporating a 50K lbs. load cell as the process sensing feedback element (see Figure 9). The system is similar to current TVC actuators except that the displacement transducer required for nozzle position control is replaced by a load transducer. The heart of the system is the Cyber Model 9410 servo controller which is an adjustable gain, proportional correction only, process controller. The servo controller receives a time-based load command signal from the ELA Position and Air Load Profile Command System and compares it real time to an actual applied load feedback signal from the 50K lbs. load cell. Any difference between the command and feedback signals will be amplified, with an adjustable amplifier, and sent as a correction signal to the Moog Model 72-103 servo valve. The magnitude of the correction signal is proportional to the load difference and is reverse phase to the sign of the difference. The Moog servo valve controls hydraulic fluid flow rate and direction into the Miller hydraulic cylinder. The hydraulic fluid flow rate, and corresponding cylinder piston velocity, is proportional to the magnitude of the correction signal. The hydraulic cylinder piston will displace until the spring rate of the structure that the cylinder is connected to (support system, engine simulator, ELA, and flexures) develops a load equal to the load command, equalizing the load cell feedback signal with the command signal.

8.3

The maximum load capability of the system is determined by the hydraulic supply pressure and the cylinder piston area. For static or slow motions of the engine simulator, the maximum cylinder load capability is 49,500 lbs. (79,200 lbs. at ELA due to support system geometry). At design maximum engine simulator velocity of 17.5 deg/sec, the maximum cylinder load capability is 33,000 lbs. (52,800 lbs. at ELA) due to pressure losses from a 60 gpm flow in the Moog servo valve. The Moog servo valve incorporates a pressure bypass mechanism that can be adjusted to limit maximum load at any value below the maximums indicated above.

8.4

A second signal output of the 50K lbs. load cell is connected to the Data Acquisition System for continuous recording of applied loads during test. A cylinder extension is used to configure the load system to the same length as the Friction Load System for ease of installation in the Structural Support System.

8.5

As noted in Section 8.2, a load difference or "error" between the load command and feedback will cause a displacement of the cylinder piston. Conversely, if a displacement of the piston is required, such as motion of the engine simulator from ELA positioning, a load error must occur to allow that piston displacement. With proper process loop tuning, the load errors can be minimized for a dynamic system. Figures 10 and 11 show the expected load tracking capability of the Air Load Control System based on previous experience with similar dynamic load control systems at Rockwell SSD. The upper part of both figures shows an idealized engine nozzle displacement flight profile incorporating position holds, slow movement, and rapid movement at 17.5 deg/sec. The postion scale is referenced to +/- 100% ELA stroke from a nozzle centered position.

The lower part of Figure 10 shows the predicted system response for a slow-ramp air load profile. When the ELA or engine simulator is static, there is little or no load error. As the ELA velocity increases, the load tracking error increases proportionally. With optimally sized and tuned servo-based load control systems, previous load error performance has been typically < +/- 3 percent maximum load for static conditions, and < +/- 10 percent maximum load for dynamic systems, with piston velocities corresponding to the 17.5 deg/sec design maximum.

The lower part of Figure 11 shows the predicted system response for a sinusoidal air load profile. For the first 2 sec of the curve, small but measureable load errors are caused by spring rate deflections of the structural support system, ELA, and flexures when the load is changing rapidly. When the load magnitude peaks, the spring rate deflections stabilize and the load error approaches zero. To minimize this type of error, the structural support system will be as stiff as possible, leaving the required ELA flexure stiffness as the primary stiffness error cause. For the rest of the curve, the ELA/engine simulator displacements add or subtract errors, either increasing or decreasing feedback wave form distortions similar to the ramp air load profile. A randomized air load flight profile would typically include elements of both ramp and sinusoidal profiles.

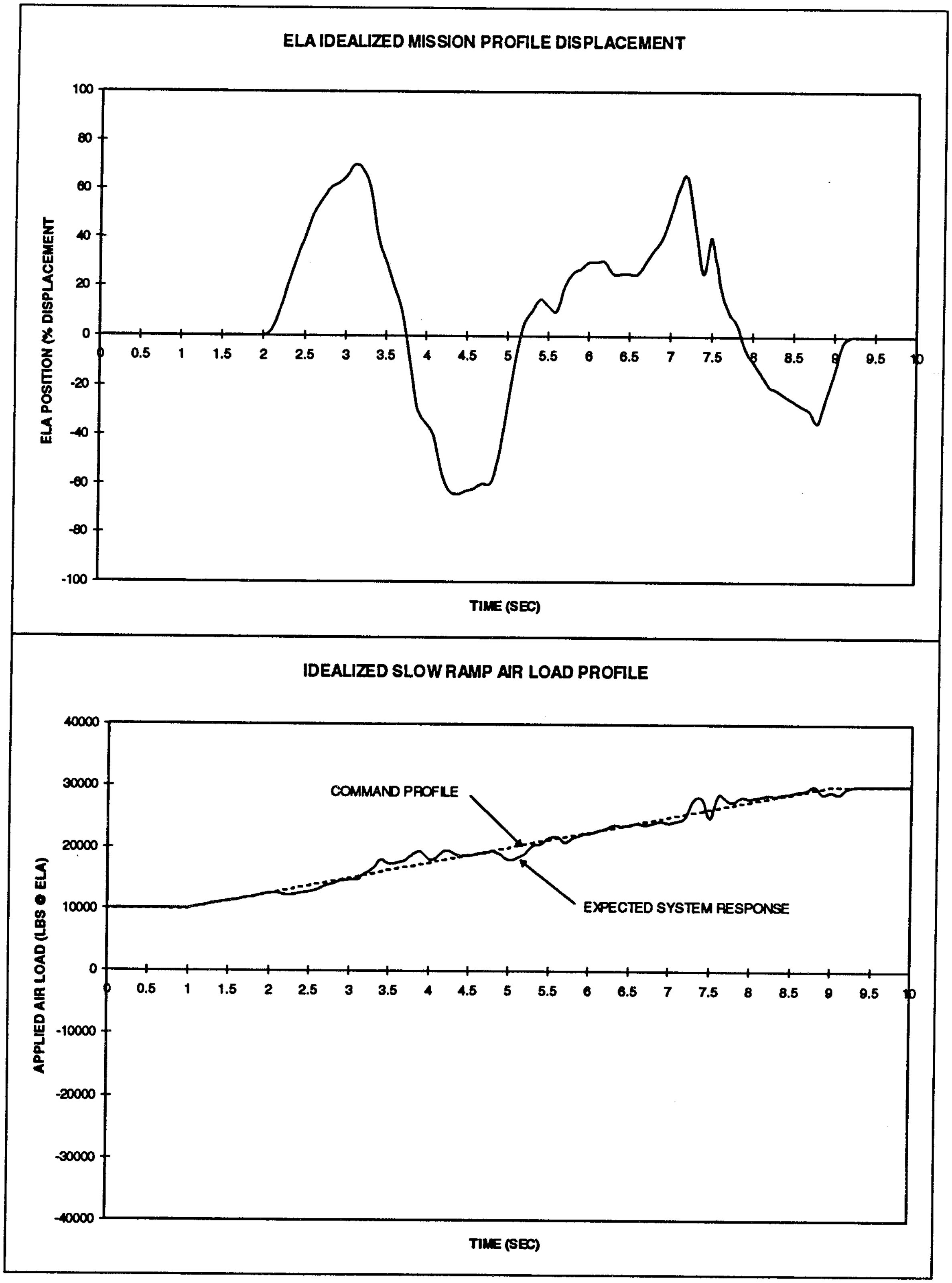


Figure 10 - Air Load Profile Control System Ramp Load Response

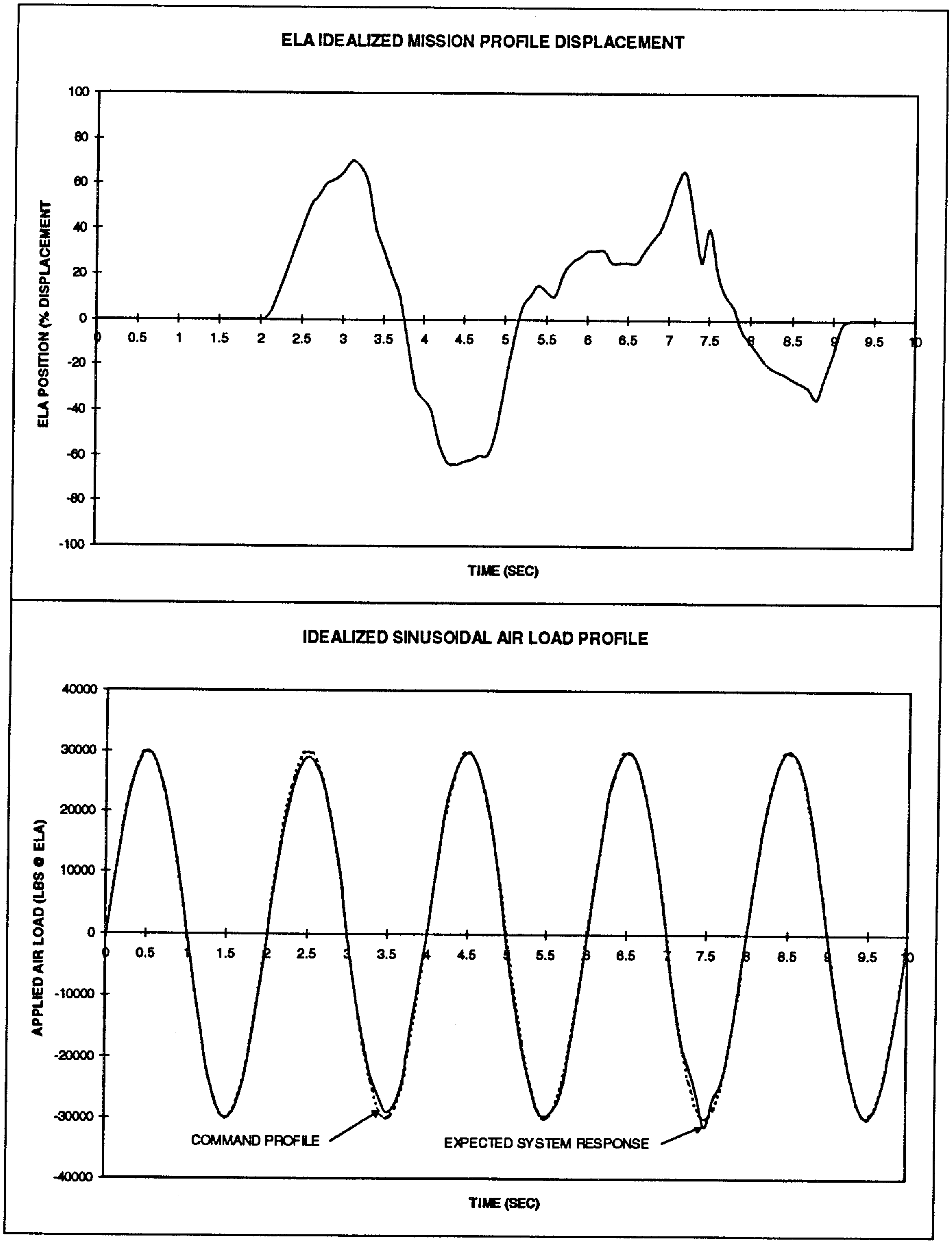


Figure 11 - Air Load Profile Control System Sinusoidal Load Response

SECTION 9.0 - CONSTANT LOAD SYSTEM

9.1

The constant load system is designed to apply a steady state load magnitude to the ELA through the engine simulator. The system will be able to apply both positive and negative moment loads referenced to the engine simulator pivot. The system is designed to maintain load with engine simulator velocities from 0 - 35 deg/sec.

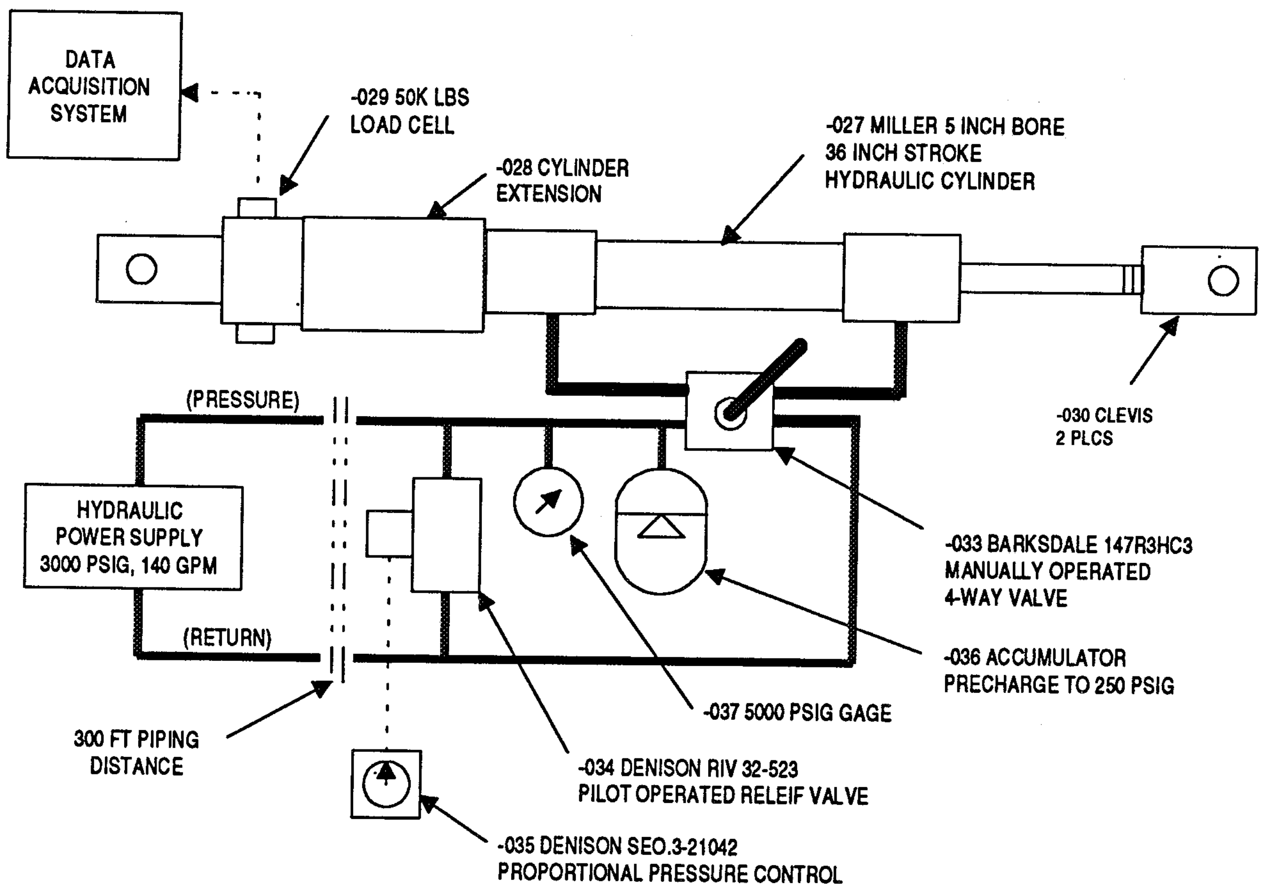


Figure 12 - Constant Load System

9.2

The Constant Load System is configured as a single-acting cylinder pressurized by the SSD Laboratories and Test pumping station with a constant volume flow rate of 140 gpm and a maximum pressure capability of 5000 psig. A manually operated high-flow, four-way valve will be installed at the cylinder to direct the pressure and flow to the correct side of the cylinder for the required test loading condition. The opposite side of the cylinder will simultaneously be connected to the pump station return. The hydraulic cylinder will be modified with multiple input ports on both sides of the cylinder to minimize flow pressure losses.

9.3

The standard way to control the pressure output of a constant volume pump is use an adjustable relief valve set at the desired putput pressure. This relief valve bypasses all flow to the pump return when there is no flow demand and bypasses a partial flow when there is flow demand. This bypass is normally done at or near the pump; this results in the feedline fluid between the SSD Laboratories and Test pump station and test site (300 ft.) being pressurized and static for a stationary hydraulic cylinder piston. On flow demand, due to ELA and engine simulator movement, the fluid in the feed lines must accelerate to the required flowrate with resultant dynamic and frictional pressure changes at the cylinder location.

This system locates an adjustable high-flow, pilot-operated relief valve at the hydraulic cylinder location which will bypass all pump flow, allowing the feed lines to maintain a constant fluid velocity and minimize acceleration effects. The high-flow relief valve maximum pressure is 3000 psig. The pump station relief valves will be set at 3300 psig for redundant safety and to prevent normal flow bypass at the pump station.

For cylinder piston motions that require additional fluid to flow to the pressurized side of the cylinder, the relief valve will partially close, allowing fluid to divert to the cylinder. Flow out of the unpressurized side of the cylinder will be added to the reduced pump station return flow through the relief valve, resulting in constant flow in the feed lines.

For cylinder piston motions that expel fluid from the pressurized side of the cylinder, the relief valve opens farther, allowing increased flow to the pump return line, enabling the unpressurized side of the cylinder to be back-filled from the return line

An accumulator is located upstream of the four-way valve to minimize local pressure impulse surges caused by accelerations of the cylinder piston.

9.4

A 50K-lb. load cell is installed in the Constant Load system to measure and record continuous load data during test. A cylinder extension is used to connect the hydraulic cylinder to the load cell allowing the Constant Load System length to match the Friction Control System length for ease of mechanical setup.

9.5

Pressure and load control adjustments are performed by remotely controlling the pilot stage pressure of the high-flow relief valve with a Denison proportional pressure controller. The 50K-lb. load cell and the 5000 psig pressure gage will be monitored until the correct test load and pressure are set.

Maximum load capability at 3000 psig is 49,500 lbs. (79,200 lbs. at ELA due to support system geometry) and minimum adjustable load is 3000 lbs. (4800 lbs. at ELA).

9.6

As noted in Section 9.2, constant load errors are caused by pressure surges and flow losses occurring in a dynamic system. The Constant Load System configuration and component sizing is designed to maintain a load accuracy of < +/- 10 percent for all loads and typically < +/- 5 percent for loads > 20K lbs. from 0 - 35 deg/sec engine simulator motion. Figure 13 shows the expected system response to a step function command signal to the ELA. The upper part of the figure shows the step function and an idealized ELA response. The lower part of the curve shows the expected response of the load system as it follows the motion of the ELA and engine simulator.

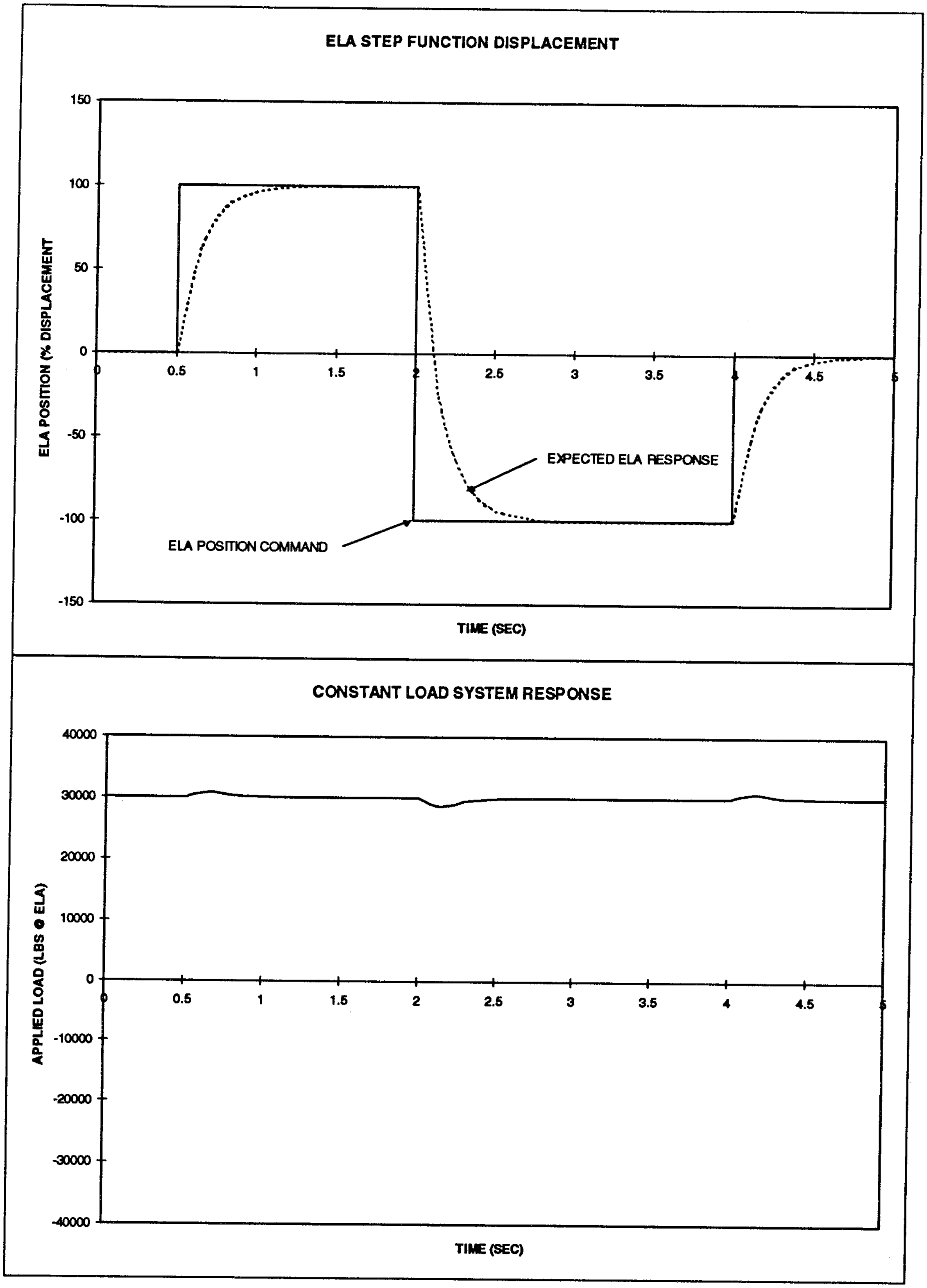


Figure 13 - Constant Load System Response

SECTION 10.0 - FRICTION LOAD SYSTEM

10.1

The friction load control system is designed as a passive system that will resist motion of the engine simulator providing a constant opposing force to motion, regardless of the angular velocity of the simulator. The load must reduce to zero for static positions of the engine simulator, even if other engine loads are actively applied.

10.2

The system design consists of a double-acting hydraulic cylinder (piston rod on both cylinder ends and equal pressure areas on both sides of the center position) with two opposing adjustable relief/check valves connecting the tension and compression sides of the cylinder (see Figure 14). The relief/check valves allow flow in one direction only and require a differential pressure, from inlet to outlet, equal to a spring preload to enable that flow. The relief/check valves are designed with low spring rates to maintain a relatively constant differential pressure over a wide range of flow rates. This differential pressure is simultaneously applied to the center piston of the hydraulic cylinder and creates a load between the piston rod and the cylinder barrel. From a static position, this load has to be applied to the piston to allow motion in either direction.

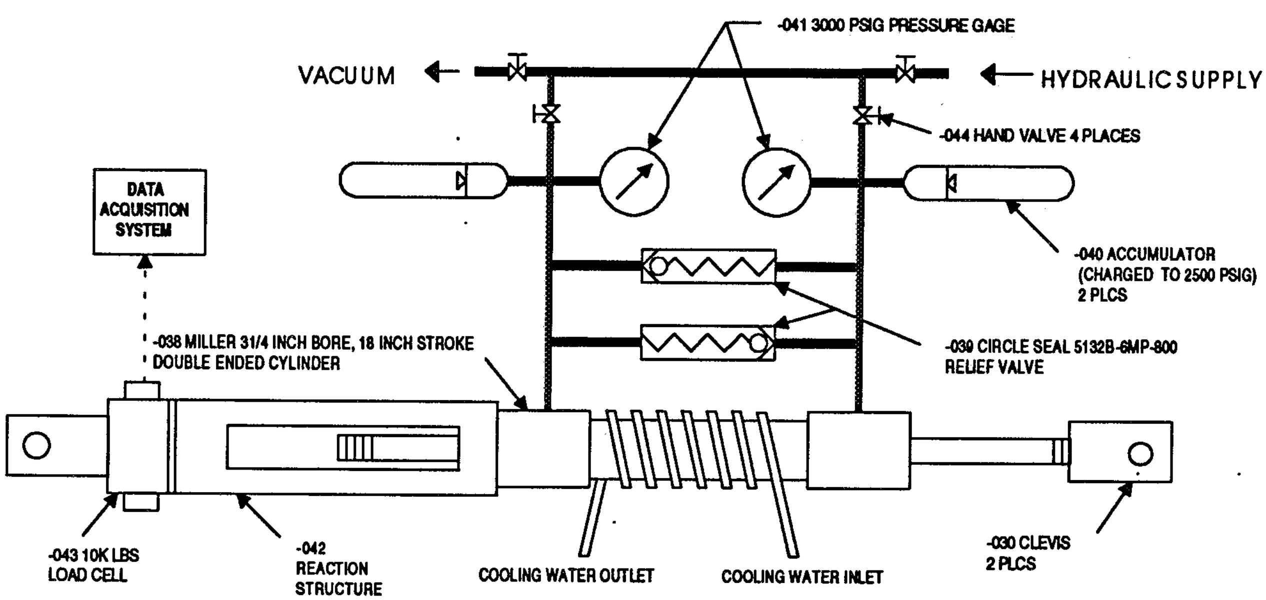


Figure 14 - Friction Control Cylinder Assembly

10.3

Shuttle data indicates an approximate friction load of 7500 lbs. at the TVC actuator location, which equates to 6250 lbs. at the friction control cylinder as a result of the test stand geometry. This 6250 load will be developed with a differential pressure of 918 psid across the cylinder piston and through the relief/check valves. Pressure gages of 3000 psig will be installed at each cylinder port to monitor check valve performance. At a maximum design engine simulator rotation speed of 17.5 deg/sec, the flow rate through the relief/check valves will be 20 gal/min of hydraulic fluid. Maximum error for flow and cracking pressure of the relief/check valves is +/- 50 psig at a 918 psid setting. Friction load accuracy should be 6250 +/- 340 lbs at the friction cylinder and 7500 +/- 400 lbs. at the ELA. Friction load magnitude can be adjusted by changing the cracking pressure of the relief/check valves.

10.4

The friction system operates properly when a movement of the engine simulator results in a corresponding volume of hydraulic fluid flowing through the relief/check valves. This requires the working fluid to be "incompressible" and devoid of any gas pockets or bubbles. To prevent gas entrapment, an evacuation and fill system will be installed on the friction cylinder (see Figure 14). Both sides of the cylinder will be evacuated and then back-filled with hydraulic fluid. A second isolation valve will be used for redundant shutoff.

10.5

The duplication of friction with flow and pressure drop will cause a heat buildup in the system and an increase in fluid volume and cylinder size. In this closed system, the differential expansion between the hydraulic fluid and the cylinder barrel will result in a baseline pressure rise for the system. Active water cooling will be used to maintain the fluid temperature between 50 - 100°F to maximize performance and minimize pressure rise. As a safety measure, a 2500 psig precharged accumulator will be installed at each cylinder port to prevent an over-pressure condition. Below 2500 psig, all flow to the accumulators is blocked, resulting in a locked system. At 2500 psig the accumulators will allow the small increase in fluid volume to flow into the reservoir, eliminating further pressure increase.

10.6

A reaction structure will be connected to the cylinder body to react friction loads into the structural support system and provide clearance for the unresticted motion of the back side cylinder rod. A 10,000-lb. load cell will be included in the assembly to allow continuous data acquisition of friction loads during test. The support structure between the friction cylinder and the engine simulator pivot point will be as stiff as possible to assure that engine simulator motions will move the cylinder piston and not deform support structure.

10.7

Figure 15 shows the expected friction system response to ELA or engine simulator ramp displacements with abrupt changes in direction and velocity. The upper part of the figure is idealized displacement of the ELA or engine simulator referenced to time. The abrupt velocity changes shown are physically impossible, but are presented for a basis of reference. The lower part of the figure presents the expected friction system response to the idealized motion. Although minimized, hydraulic fluid compression and structural deflection will cause a small amount of lag and overshoot for friction load changes and reversals caused by abrupt changes in velocity and direction. The continuous data acquisition will record these deviations.

10.8

Figure 16 shows the expected friction response to ELA or engine simulator displacements with gradual changes in velocity, represented by a haversine displacement referenced to time in the upper part of the figure. The lower part of the figure shows the friction system response to gradual velocity changes indicating less lag and overshoot of the opposing friction load.

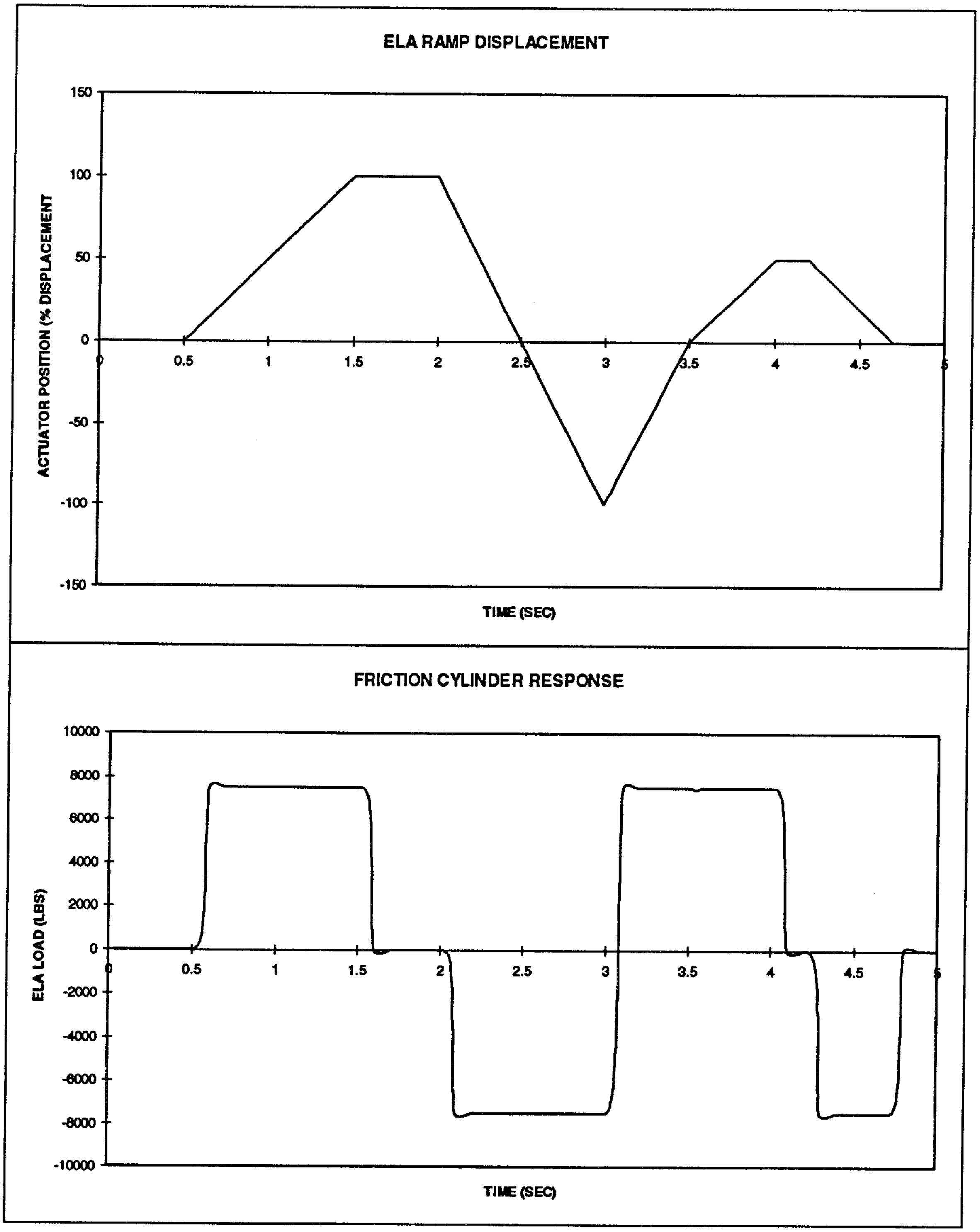


Figure 15 - Abrupt Change Friction System Response

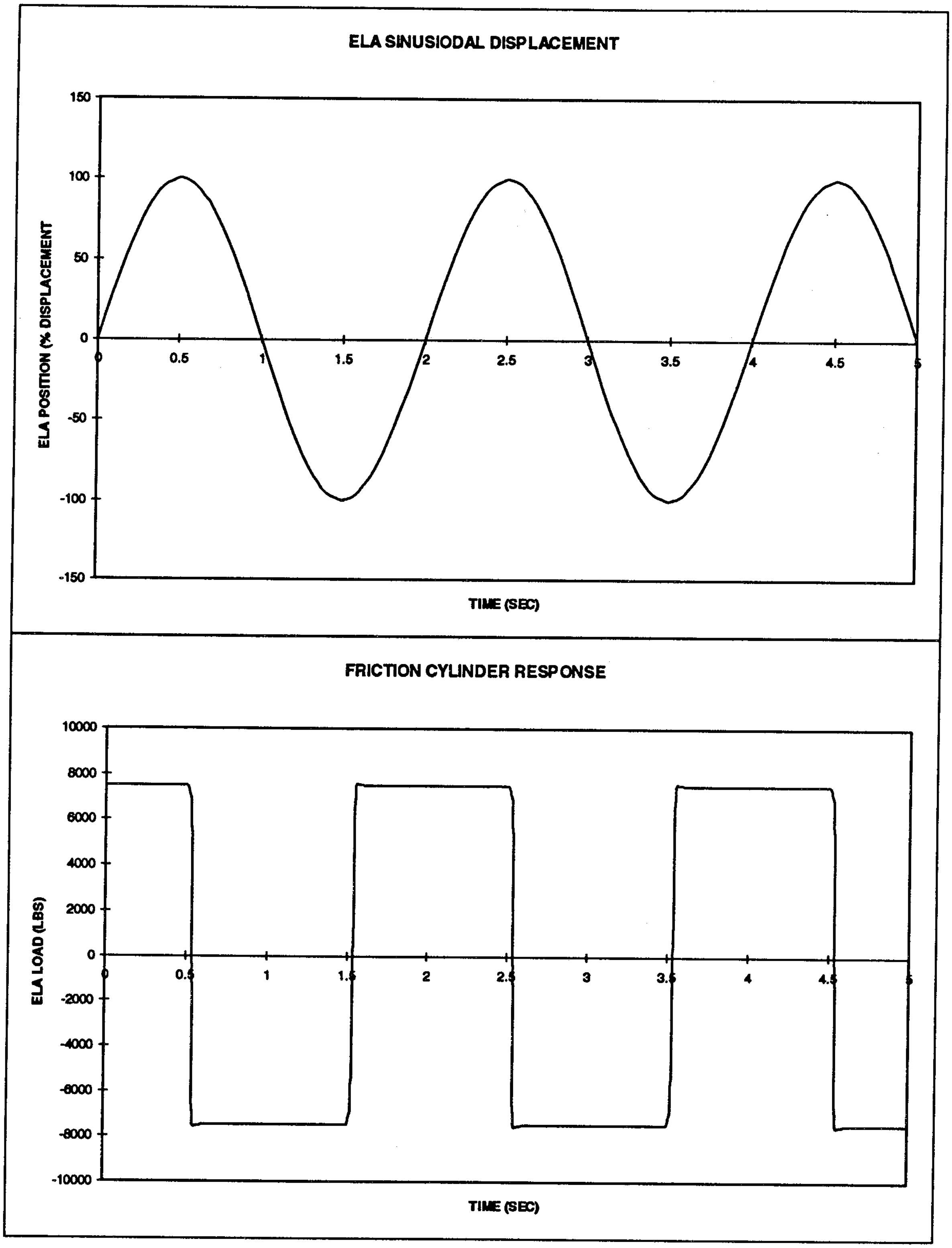


Figure 16 - Gradual Change Friction System Response

SECTION 11.0 - DATA ACQUISITION SYSTEM

11.1

The Laboratory Data Acquisition System is located within Bldg. 288 approximately 150 ft from the proposed ELA Test Facility location. This location provides a relatively short data transfer distance from the test site. Existing data system connection cabling is installed to locations within 50 ft of the test facility site, simplifying installation.

The data system is designed to receive analog voltages from various sensors, convert the voltage signals to digital format, and record and process the resultant digital data. ELA test sensors that require signal conditioning to convert the sensor output to a level acceptable to the data system will be conditioned by the -046 Cyber Signal Conditioning at the test facility site and connected to the -045 Data Acquisition System (see Figure 17). Sensors not requiring conditioning will be connected direct. Signal conditioning requirements for the ELA position sensor will not be known untill the specific sensor system for the test ELA is identified.

11.2

The basic setup programming for the Data Acquisition System requires entering parameters for each data sensor channel into a DDAAS "INPUT SETUP" form. These parameters include the sampling rate necessary for post test analysis, the full scale input voltage range for each class of input, and the calibration scaling factor for each specific input channel. Input voltages up to 20 V peak to peak can be accommodated. The entire data base can be sampled at up to 32,000 samples per second. All data is acquired synchronously.

11.3

All data is collected using a Hewlett Packard HP 3565 Analog to Digital Conversion Front End controlled by an HP 9000 Series Model 715/75 UNIX Workstation. The data analysis requirements determine the method of acquisition. For time based analysis, data is acquired to time history files in the front end mass storage device, and processed post test. For frequency based analysis where time history data storage is not required, frequency data is accumulated from the A/D and plotted real time. For either type of acquisition, scan initiation can be triggered on an event, on any data channel at any level, or manually via the operators console.

11.4

Data analysis is available for all channels. Analysis can be as simple as time history plotting, or as involved as frequency and phase analysis. Raw and processed data is saved to archive on a removable rewritable optical disk and can be provided to data requesters in hard copy plot format, mass media storage (floppy disk), or transferred to other systems connected to the LAN. Figure 18 shows an example of a typical hard copy output for a time history plotting. This particular example utilizes a much finer time resolution than would be required for ELA testing but it displays the product format.

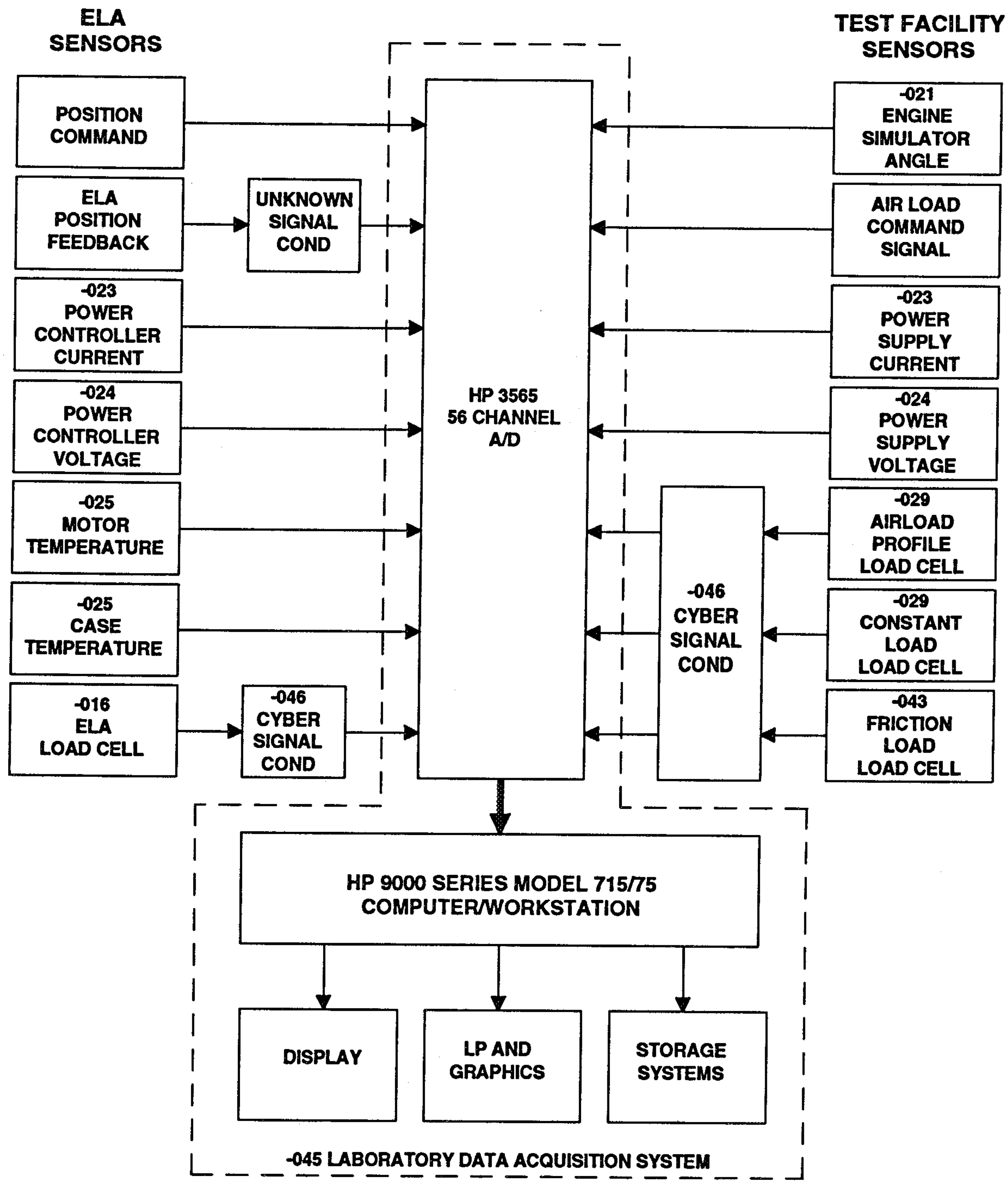


Figure 17 - Data Acquisition System Block Diagram

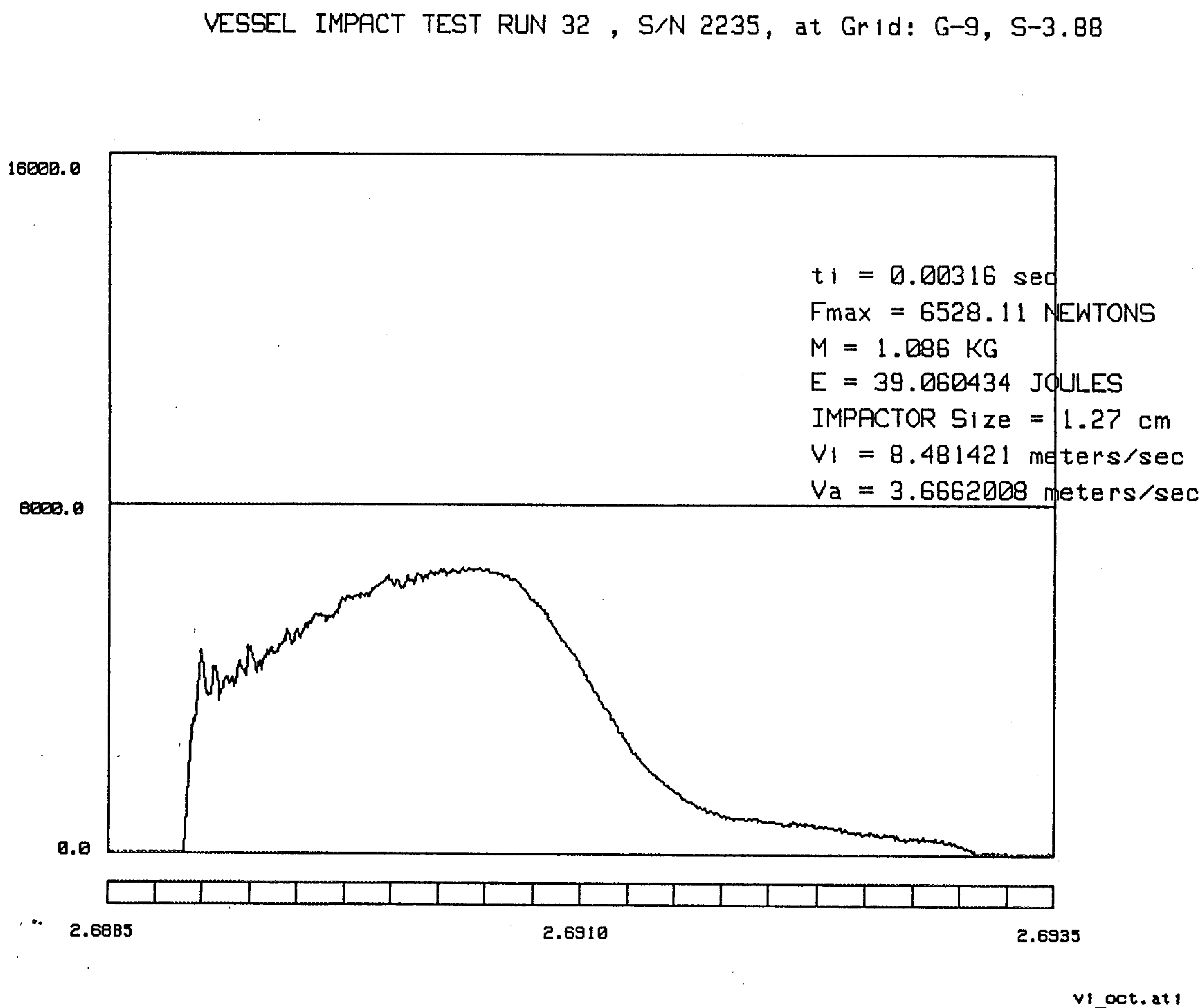


Figure 18 - Data Acquisition Hard Copy Format

SECTION 12.0 - DESIGN VERIFICATION TEST PROCEDURE

12.1

The design verification of the ELA Test Facility will consist of verifying the performance of the active facility systems and document the baseline ELA support fixture stiffness.

The systems of primary interest are the Electrical Power Control System, the Air Load Profile Load System, The Constant Load System, and the Friction Control System. The other test facility systems will be functioning during the verification of the above systems and will be verified in process.

12.2

The verification of the Electrical Power Control System will consist of an operational checkout up to the ELA Power Controller which will not be available.

12.2.1

Maximum voltage and current verification:

Connect the Laboratory Power Supply to the Fail-safe panel and set programmed voltage and current limits to 370 V DC and 315 Amp respectively.

Connect the -023 current transducer and -024 voltage transducer to the Data Acquisition System.

Connect output of fail-safe panel to a suitable electrical load and clear area of all personnel. Initiate continuous data recording.

Adjust power supply voltage from 0 - 350 V - 0 and verify voltage and current output and control.

12.2.2

Fail-safe Panel checkout:

Set programmed voltage limits to 280 V DC. Disconnect fail-safe panel output from load and clear area of personnel.

Initiate data acquisition and adjust voltage from 0 - 280 V DC and verify power interrupt. Adjust voltage output to zero.

Reset power interrupt and connect fail-safe panel output to a 1 ohm load. Set programmed current limits to 200 Amp and clear area of personnel.

Initiate data acquisition and adjust voltage from 0 - 200 V DC and verify current and power interrupt. Adjust voltage output to zero.

12.3

The verification of performance of the Air Load Profile Load System, the Constant Load System, and the Friction Control System will require a movement of the Engine Mass Simulator System. This motion will be performed by a manually controlled hydraulic actuator to replace the ELA position control actuator.

The replacement actuator will be a Miller 7 inch bore hydraulic cylinder with a 12 inch stroke (see Figure 19). A -033 high flow 4-way valve will control the position of the replacement actuator. When the 4-way valve is centered, the fluid is locked in the cylinder resulting in a fixed position. When the control handle is moved to flow fluid in one direction or the other, the piston will displace until it bottoms in the cylinder barrel or the control valve is returned to center. A -048 fixture will be used adjust the limit of the control valve handle to control the rate of fluid flow and piston velocity. This adjustment will enable the Engine Simulator to be driven at various velocities to evaluate control systems.

The replacement actuator will be positioned in the Shuttle TVC geometry and connected to the Engine Simulator and Structural Support system in the same manner as an ELA including the -016 load cell. No flexures will be used. The Shuttle geometry combined with the 12 (+/-6) inch stroke will give an engine simulator movement of approximately +/- 12 degrees before the piston bottoms in the cylinder barrel. The replacement actuator will have a maximum load capability of 94,000 lbs. @ 3000 psig and a resultant moment capability of 2.8×10^6 in-lbs. This moment capability will easily overcome and be limited by the moment capability of the test facility loading systems which have a maximum moment of 2.4×10^6 in-lbs. This will allow the replacement actuator to move the Engine Simulator to the velocities required for systems evaluation.

12.4

The verification of the Friction Control System will consist of an evaluation of the load response with manually generated ramp/hold and saw tooth wave forms.

12.4.1

Friction Control System checkout:

Connect Friction Control System and replacement ELA actuator to the Engine Simulator. Set the Engine Simulator Mass to the minimum 2000 slug-ft^2. Verify connection and operation of the -043 Load Cell, -016 Load Cell, and -021 Rotational Transducer with the Data Acquisition System. Initiate data

Adjust the -048 limit fixture to control an Engine Simulator velocity of 2 deg/sec. Initiate data acquisition.

Operate 4-way control valve to displace actuator full in both directions until the piston bottoms in the cylinder barrel. Hold for 5 seconds at each end stop before reversal. Return actuator to a center position and hold 5 seconds for an intermediate stop point on each flow direction. Repeat each direction four times.

Operate 4-way control valve to near full displacement in both directions with no hesitation on flow reversal. Repeat each direction four times.

Repeat the two 4-way valve operations at Engine Simulator Velocities of 5, 10, 15, and 20 deg/sec.

Verify friction load tracking is acceptable and that internal friction cylinder pressures do not exceed 2500 psig.

12.5

Verification of the Air Load Profile Load System will consist of verification of load control for static and sinusoidal loads for various load magnitudes and manually controlled Engine Simulator velocities as noted in section 12.4.

12.5.1

Air Load Profile Load System checkout:

Remove the Friction Control System from the test facility and install the Air Load Profile System with no changes to the replacement ELA system. Verify the -029 Load Cell is connected to the data acquisition system and initiate data recording.

Set ELA replacement actuator at a center position with locked flow. Adjust ELA Position and Air Load Command System to a +5,000 lbs static set point for the load system. Verify accuracy and control.

Perform 4-way valve operations with the ELA replacement actuator to perform Engine Simulator displacements for 2, 5, 10, 15, and 20 deg/sec as noted in Section 12.4.1. Verify load tracking accuracy at each Engine Simulator Velocity.

Repeat the above motion tests for static load commands of -5000 lbs, +/-10,000 lbs, +/-20,000 lbs, and +/-40,000 lbs. Verify load tracking at all speeds and loads.

Program ELA Position and Air Load Command System to produce a sinusoidal air load command at 0.5 hertz with max/min at +/- 5000 lbs. and repeat the static load command Engine Simulator motion tests noted above. Verify load tracking accuracy.

Repeat the 0.5 hertz sinusoidal load command tests at +/-10,000 lbs, +/- 20,000 lbs, and +/-40,000 lbs.

12.6

The verification of the Constant Load System will be very similar to the static load test for the Air Load Profile System except that higher Engine Simulator Speeds will be attempted. Since both the Constant Load System and the ELA replacement actuator operate from the same pressure source (controlled by the Constant Load System), sufficient differential load may not be available at low load magnitudes to move hydraulic fluid in or out of the Constant Load or ELA replacement cylinders to achieve the desired Engine Simulator velocity.

12.6.1

Constant Load System checkout:

Replace the Air Load Profile System with the Constant Load System with no changes to the replacement ELA system. Set the Laboratory Hydraulic Pump Station to 140 gpm output flow rate. Verify the -029 Load Cell is connected to the Data Acquisition System and Initiate Data Recording.

Set ELA replacement actuator at a center position with locked flow. Adjust the -034 relief valve to achieve a +5000 lbs. load at the -029 load cell .

Perform 4-way valve operations with the ELA replacement actuator to perform Engine Simulator displacements for 2, 5, 10, 15, 25, and 35 deg/sec as noted in Section 12.4.1. Verify load tracking accuracy at each velocity.

Repeat the above motion tests for constant loads of -5000 lbs, +/-10,000 lbs, +/- 20,000 lbs, and +/- 40,000 lbs. Verify load tracking at all speeds and loads.

12.7

The determination of the baseline ELA support fixture stiffness is required to properly calculate the -015 flexure stiffness required to simulate ELA support structure. The total test system flexibility (in/lb or deg/lb) will be the sum of the two flexibility's. Each ELA geometry will have a specific baseline stiffness and must be determined separately.

12.7.1

Baseline Structural Support Stiffness Test:

Configure Structural Support System and Engine Simulator System to the test ELA geometry. Install the -016 load cell but not the -015 flexure.

Install the replacement ELA actuator and set at a center position with locked flow. Install the Air Load Profile System.

Connect a laboratory linear deflection transducer to the -014 clevis. The direction of travel is to be in-line with the ELA. Connect a second laboratory linear defection transducer to the -013 support fitting of the Engine Simulator. Direction of travel must be parallel to the first transducer. Both transducers should be referenced and attached to the laboratory floor with no connection to the Structural Support System.

Initiate data acquisition of both deflection transducers, the -016 load cell, the -029 load cell and the -021 angular position transducer. Apply Air Loads in increments of 10,000 Lbs. from zero to a maximum load of 40,000 lbs. Repeat sequence two times. Document net defection between the linear transducers.

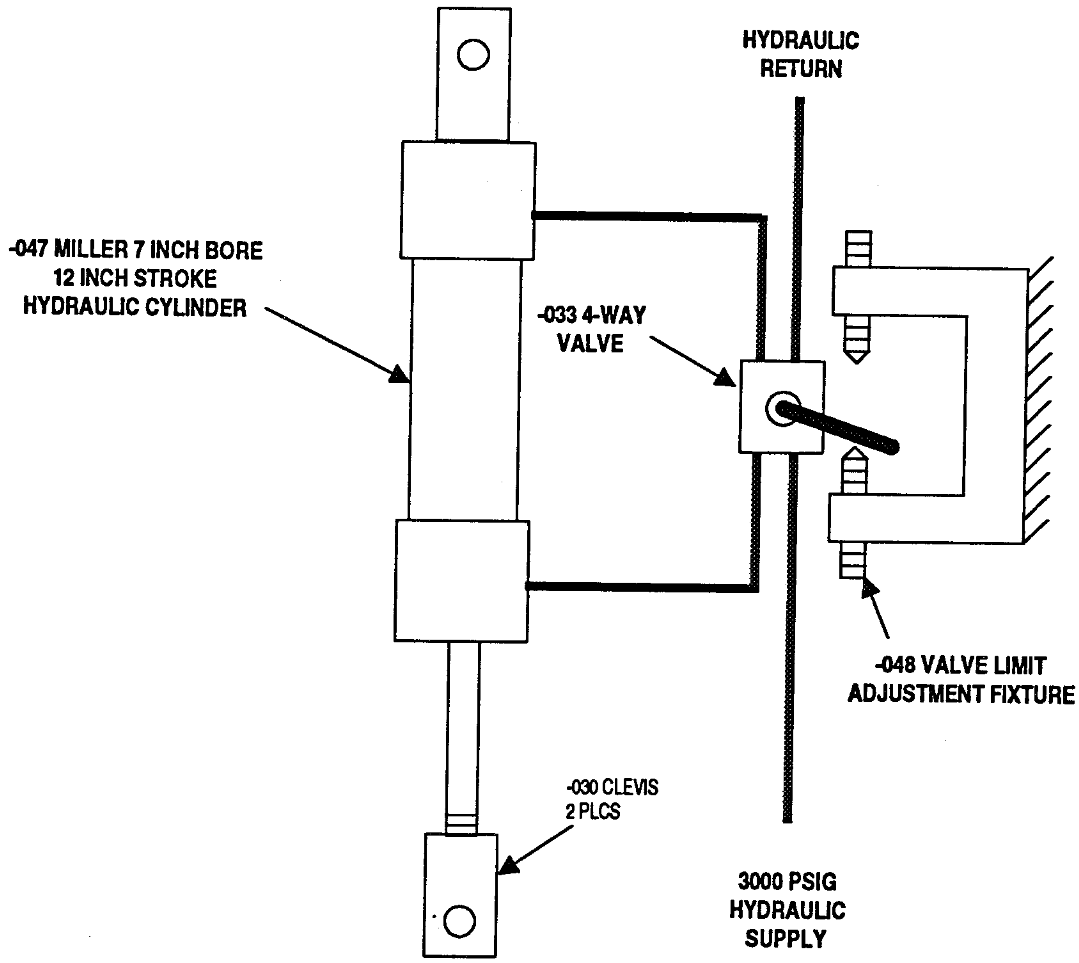


Figure 19 - Replacement ELA Actuator

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
Strategic Avionics Technology Definition Studies Subtask 3 - 1A3, Electrical Actuation (ELA) Systems Test Facility	September 30, 1994
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
J. P. Rogers	SSD94D0298
	10. Work Unit No.
9. Performing Organization Name and Address	11. Contract or Grant No.
Rockwell International Space Systems Division 12214 Lakewood Blvd. Downey, Ca. 90241	NAS9-18880
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Final 1994
National Aeronautics and Space Administration Johnson Space Center Houston, Texas 77058	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Future aerospace vehicles will require use of the Electrical Actuator systems for flight control elements. This report presents a proposed ELA Test Facility for dynamic evaluation of high power linear Electrical Actuators with primary emphasis on Thrust Vector Control actuators. Details of the mechanical design, power and control systems, and data acquisition capability of the test facility are presented. A test procedure for evaluating the performance of the ELA Test Facility is also included.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Electrical Actuation, ELA, Electro-Mechanical Actuators, EMA, Actuation, Space Shuttle, effector	Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	45	